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## Green GDP: Balancing Growth and Climate Action

### Summary

Nowadays, some nations excessively exploit their natural resources to enhance their GDP but ignore the ecological damage. Replacing GDP with “Green” GDP is an attractive yet challenging solution. Therefore, this paper defines the GGDP and evaluates its climate mitigation impacts.

First, we integrate and enhance existing methods to choose a GGDP formula with a measurable impact on climate mitigation. We compute GGDP by subtracting environmental spending (the total of net resource consumption prices and pollution treatment costs) from GDP. Next, we compare the alterations in GGDP from 2000 to 2019 in the United States and China. In the U.S., GGDP consistently exceeds **95%** of GDP, indicating a sustainable economy. Meanwhile, in China, GGDP as a proportion of GDP rose from **77.1%** to **94.8%**, indicating China’s ongoing efforts to mitigate the climate crisis.

Second, we pre-process the collected worldwide data by interpolation and normalization. To measure the impact of global climate mitigation, we choose nine secondary indicators such as GGDP from three dimensions: **economy, society, and ecology**. Then, we combine **AHP** and **CRITIC** to compute the weights of each indicator (see **Figure 7**). Based on these weights, we calculate the **Climate Mitigation Index (CMI)** and predict the CMI for the **next five years** using **GM(1,1)**. We observe that the CMI is expected to increase and reach **63** in 2024, indicating a potential to mitigate the climate crisis.

Then, we evaluate the advantages and drawbacks of implementing GGDP using **GE matrices**. The optimal point in the GE matrix signifies no drawbacks and the greatest benefits. We categorize nine indicators as being either positively or negatively impacted by the GGDP implementation, and we compare the short-term and long-term outcomes. The distances from the optimal point are predicted to be **82.51** and **66.62** for implementation and non-implementation in the next ten years, while they are **34.68** and **50.76** in the following twenty years, respectively. This indicates that GGDP justifies global replication due to its long-term benefits.

Next, we select **India** for further study and propose three policy intervention strategies to enhance India’s GGDP: conserving natural resources, recycling waste, and improving pollution treatment technology. Subsequently, we introduce the **Development Ratio**, where a value less than 1 indicates a valid intervention. The results suggest that India needs to reduce policy support over time to ensure that environmental benefits surpass intervention expenditures.

Finally, we evaluate the strengths and weaknesses of the models, analyze the **sensitivity** of the evaluation model to the Gini Coefficient, Human Development Index, and forest cover area, and confirm its stability. Additionally, we prepare a non-technical report for Indian leaders.

**Keywords:** GGDP; AHP-CRITIC; GM(1,1); GE matrix; climate mitigation

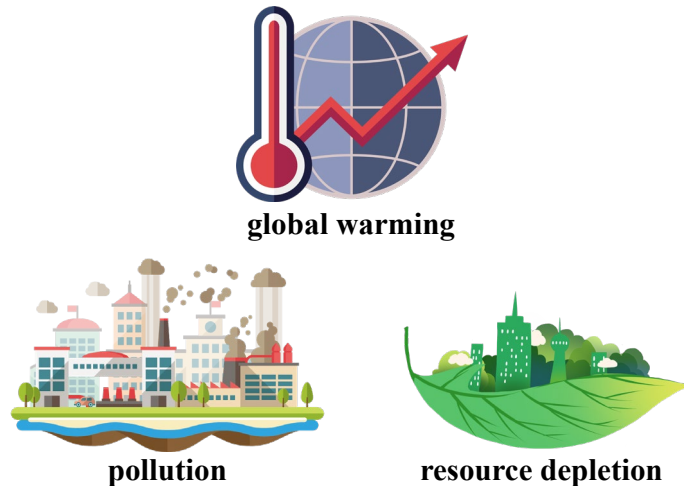
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# 1 Introduction

## 1.1 Problem Background

The Gross Domestic Product (GDP) is a widely used measure of a nation's economic well-being. However, some countries prioritize GDP growth over sustainable development, exacerbating the climate crisis, as shown in **Figure 1**. An evident surge in energy consumption across natural resources is depicted in **Figure 2**, where the scattered data points represent renewable consumption, only constituting a smaller proportion.



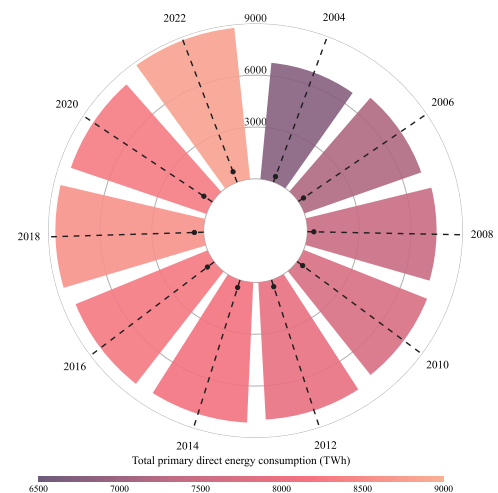
**Figure 1: Part of the climate crisis**

Therefore, it is crucial to establish a “Green” GDP (GGDP) that incorporates environmental and sustainable considerations rather than relying solely on traditional measurements. Despite the substantial challenges in implementing GGDP, concerted efforts should be made to mitigate the climate crisis.

## 1.2 Restatement of the Problem

To propose GGDP criteria, evaluate the climate mitigation impacts, compare the drawbacks and benefits of GGDP implementation, and propose potential policy strategies, we need to perform the following tasks:

- Decide on a GGDP to replace GDP for measuring economic health and quantitatively measure the impacts on climate mitigation.
- Evaluate global climate mitigation impacts using diverse indicators, with GGDP as an indicator of economic health within the evaluation system.
- Analyze both the positive and negative effects of implementing GGDP based on the previous evaluation model.
- Choose a specific nation for further analysis and write a non-technical report to present findings to the leaders.



**Figure 2: Direct energy consumption**

### 1.3 Literature Review

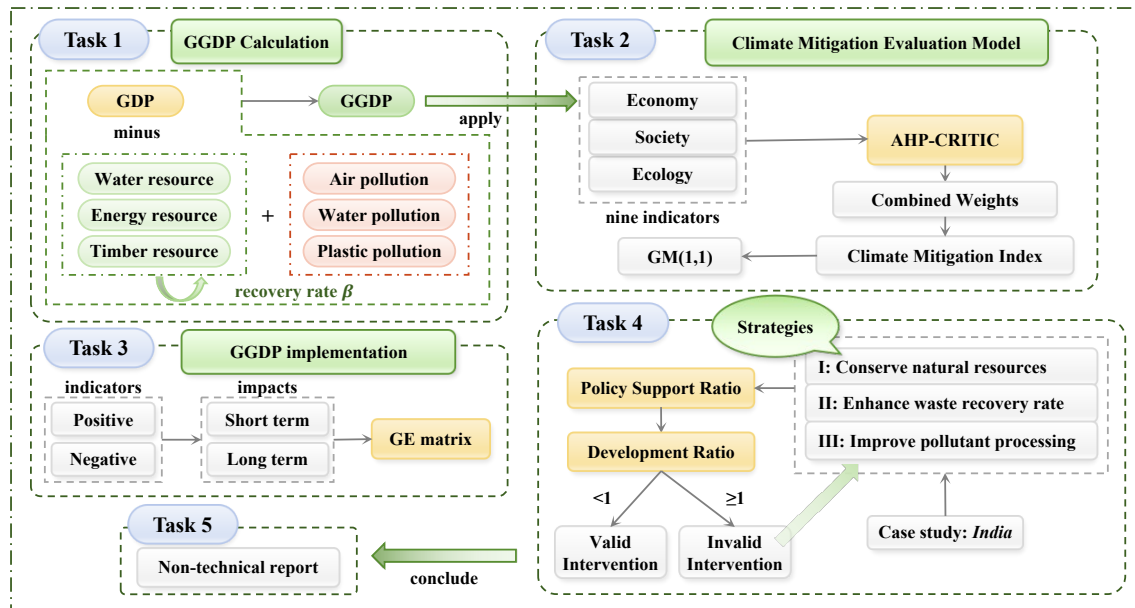
Nations enhance their GDP by excessively exploiting natural resources. It is essential to adopt GGDP for economic well-being to promote sustainable development, calculating GGDP and its impact on climate mitigation key areas of research.

Regarding defining GGDP, Talberth et al. [2] utilized the nation's capital stock, labor input, and economic openness to calculate GGDP. There was a positive nonlinear correlation between economic openness and GGDP growth. Stjepanović et al. [3] proposed a GGDP approach that quantifies the cost of ecological and environmental degradation, including costs of CO<sub>2</sub> pollution, waste, and natural resource depletion in the calculation. Sonthi et al. [4] used GDP minus natural capital, which is cost to the environment plus resource depletion, as GGDP. Wen et al. [5] considered natural resource depletion, the cost of environmental degradation, and the comprehensive utilized value of waste in their GGDP measure. In addition, some researchers analyzed the GGDP's impacts on climate mitigation and policy-making. Alfsen et al. [6] concluded that although GGDP was attractive, it was usually too complex to guide policy-making in practice. Sidjabat et al. [7] found that an environmental management system integrated with GGDP could improve the cycle of sustainability.

However, the current study lacks a standardized calculation for GGDP and global impact analysis. We integrate their work and propose GGDP, along with a quantifiable climate mitigation evaluation model.

### 1.4 Our Work

As shown in **Figure 3**, we first select a GGDP calculation approach. Then we establish an evaluation model based on economy, society, and ecology. Next, we analyze the impacts of GGDP. Finally, we discuss India and prepare a non-technical report for leaders.



**Figure 3: Flowchart of our study**

## 2 Assumptions and Justifications

As GGDP is intricate in reality and will be influenced by numerous factors, we propose the following assumptions to simplify the models:

**Assumption 1: Air pollution, water pollution, and plastic pollution are independent, they do not contain and influence each other in our calculation.**

**Justification:** To simplify our model, we do not consider the interaction between pollution in GGDP calculation.

**Assumption 2: There will be no sudden global events in the near future.**

**Justification:** The probability of a sudden global event is very low, and the international landscape is overall stable. It is reasonable to assume that occasional small-scale incidents will not significantly impact the environment.

**Assumption 3: The data we obtain from websites are accurate and reliable.**

**Justification:** We obtain our data from official websites, and we reasonably assume that they are of high quality.

**Assumption 4: The reduction in resource consumption and pollution processing costs is uniform across all types.**

**Justification:** As environmental awareness rises, people consume fewer natural resources and dispose of fewer pollutants. Assuming this change is consistent helps simplify the model.

## 3 Notations

Some important mathematical notations used in this paper are listed in **Table 1**.

**Table 1: Notations used in this paper**

Symbol	Description	Unit
$GGDP$	“Green” GDP	dollar
$G$	Gini Coefficient	%
$HDI$	Human Development Index	/
$LPI$	Living Planet Index	/
$\omega_i$	Weight of $i$ -th indicator	/
$CMI$	Climate Mitigation Index	/
$SNI$	Short-term Negative Index	/
$SPI$	Short-term Positive Index	/
$LNI$	Long-term Negative Index	/
$LPI$	Long-term Negative Index	/
$r$	Policy Support Ratio	/
$\rho$	Development Ratio	/

\*Some variables not listed here will be discussed in each section.

## 4 GGDP Selection and Calculation

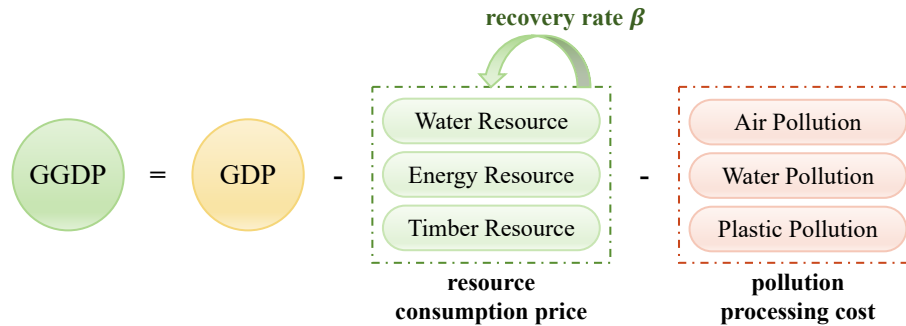
In this section, we present the GGDP calculation approach based on existing literature to ensure that GGDP implementation has measurable impacts on climate mitigation. Next, we compare the GDP and GGDP in the United States and China from 2000 to 2019.

### 4.1 GGDP Calculation

After referring to numerous kinds of literature, we find research on GGDP calculations is similar. Most of the GGDPs were calculated by GDP minus environmental costs. Combining several representative formulas <sup>[2][3][4][5]</sup> and available data, we simplify and improve the GGDP calculation, finally conclude the following formula:

$$GGDP = GDP - \sum_{i=1}^3 C_i V_i (1 - \beta_i) - \sum_{k=1}^3 P_k M_k, \quad (1)$$

where  $i$  is the type of resource (1 is water resource, 2 is energy resource, and 3 is timber resource),  $C_i$  is the annual consumption volume of resource  $i$ ,  $V_i$  is the estimating price of resource  $i$  per unit volume,  $\beta_i$  is the recovery rate of resource  $i$ ;  $k$  is the type of pollution (1 is air pollution, 2 is water pollution, 3 is plastic pollution),  $P_k$  is the volume of pollutants  $i$ ,  $M_k$  is the costs of processing the pollutants  $i$  per unit volume.

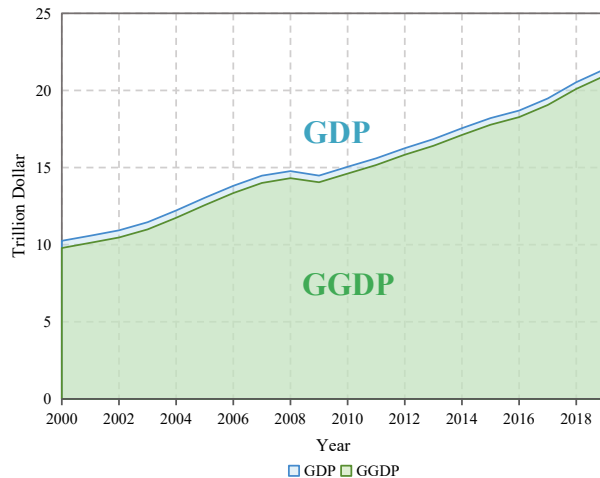


**Figure 4: Calculation of GGDP**

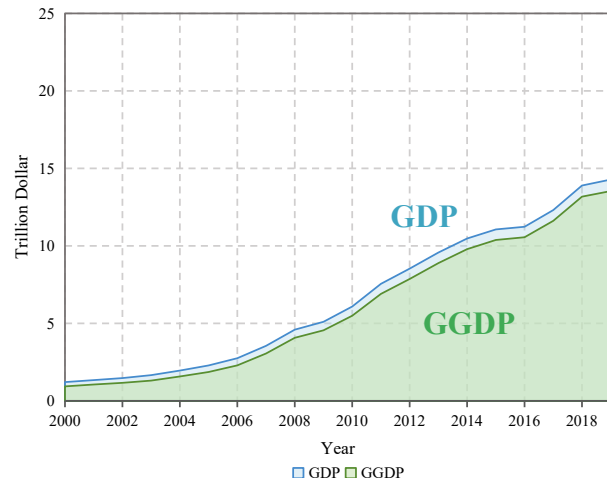
The selected approach can have measurable impacts on climate mitigation by considering the consequences of excessive resource use and pollution. For example, if a nation clears its trees to boost GDP but causes carbon emissions, penalties will be imposed for timber consumption and air pollution in GGDP.

### 4.2 Result Analysis

**Figure 5** and **Figure 6** present the GDP and GGDP trends from 2000 to 2019 for the United States and China, respectively. The growth trends of both GDP and GGDP exhibit similarities in the two countries. Notably, in 2000, the GDP and GGDP in the United States were approximately ten times higher than those in China. Over time, this gap gradually diminished, and by 2019, the GDP and GGDP in the United States were approximately 1.5 times that of China.



**Figure 5: GDP and GGDP in the US**



**Figure 6: GDP and GGDP in China**

In the United States, GGDP accounted for 95.5% of the GDP in 2000, and this proportion increased to 98.0% by 2019. This shift suggests that the United States demonstrates a robust economic condition, as it allocates a relatively small portion of its GDP to counterbalance the adverse effects of resource consumption and environmental pollution. Furthermore, in China, GGDP represented 77.1% of the GDP in 2000, which surged to 94.8% by 2019. This notable increase indicates that China has made progress in bolstering its economic health, approaching the levels observed in the United States.

## 5 Evaluation Model of Climate Mitigation and GGDP Impacts

Climate mitigation refers to reducing the negative impacts of the climate crisis. In the absence of a universally recognized definition for the climate crisis, we evaluate the impact of climate mitigation by assuming the implementation of GGDP.

### 5.1 Indicator Selection

After reviewing an extensive body of literature, we determine that the climate crisis is reflected in the domains of economy, society, and ecology.

#### 5.1.1 Economy

The economic impacts of the climate crisis, such as extreme weather events and natural disasters, primarily manifest in a nation's GGDP, GDP per capita, and Gini Coefficient [8]. Specifically, the deterioration of infrastructure, decline in agricultural productivity, and escalation of healthcare costs all contribute to diminished growth in GGDP. Furthermore, if a nation experiences reduced agricultural productivity due to climate-related factors, this has the potential to lower its GDP per capita. Additionally, climate-related disasters can disproportionately affect lower-income populations and exacerbate wealth inequality. The Gini Coefficient is calculated by

$$G = \frac{\sum_{i=1}^{n-1} (y_i + y_{i+1})(x_{i+1} - x_i)}{2 \sum_{i=1}^n y_i}, \quad (2)$$

where  $n$  is the number of income brackets,  $(x_i, y_i)$  is the Coordinates of the Lorenz curve. This formula outlines the ratio of the area between the Lorenz curve and the line of perfect equality to the total area below the line of perfect equality.

### 5.1.2 Society

The social impacts of the climate crisis include the happiness index, population, and human development index. The happiness index assesses subjective well-being, encompassing dimensions such as social support, autonomy in life choices, and societal security. The climate crisis can exert influence on these dimensions by causing displacement due to natural disasters, heightening anxiety regarding extreme weather events, and instilling concerns about future sustainability. Meanwhile, factors such as access to resources, healthcare, and employment in the face of climate-related challenges can impact population trends.

The Human Development Index incorporates variables such as life expectancy, education, and per capita income. The climate crisis can exert an influence on these constituents by impacting life expectancy through heightened health risks, disrupting education via infrastructure damage and resource constraints, and affecting income due to diminished economic productivity and increased expenses associated with climate adaptation and recovery endeavors:

$$HDI = \left( \frac{I_{health} \times I_{education} \times I_{income}}{3} \right)^{1/3}, \quad (3)$$

where  $I_{health}$  represents the index for life expectancy,  $I_{education}$  represents the index for mean years of schooling, and  $I_{income}$  represents the index for Gross National Income per capita.

### 5.1.3 Ecology

The ecological impacts of climate include global temperature, the Living Planet Index, and forest cover area [9]. The global rise in temperature, often referred to as global warming, is a key indicator of the climate crisis. This increase has widespread effects, including more frequent and severe heatwaves, altered precipitation patterns, and the melting of polar ice. These changes can directly impact ecosystems, agriculture, and human health, among other factors.

The climate crisis poses a significant threat to biodiversity. The Living Planet Index serves as an indicator for assessing the state of global biodiversity. As the climate crisis escalates, this index increasingly reflects the profound impact on our planet's ecological well-being:

$$LPI = \frac{\sum_{i=1}^n (p_{i,t} / p_{i,1970})}{n} \times 100, \quad (4)$$



where  $p_{i,t}$  is the population size of the  $i$ -th species at a time  $t$ ,  $p_{i,1970}$  is the population size of the  $i$ -th species in 1970, and  $n$  is the total number of species included in the index.

Forests maintain the global carbon cycle and preserve biodiversity. The ongoing climate crisis poses significant threats to forests, including deforestation, forest degradation, and an escalation of forest fires, which can have profound implications for carbon sequestration, wildlife habitats, and local climates.

In summary, we employ nine secondary indicators listed in **Table 2**.

**Table 2: Indicator description**

Level I	Level II	Description	Unit
Economy	GGDP	“Green” GDP	dollar
	GDP per capita	GDP divided by the total population of a country	dollar
	Gini Coefficient	Economic inequality within a population	-
	Happiness Index	Subjective well-being and quality of life of inhabitants	-
Society	Population	Total number of people living in a country	-
	Human Development Index	Average achievements in a country	-
	Temperature	Warmth or coldness of an environment	°C
Ecology	Living Planet Index	Health of the planet’s ecosystems (population trends of vertebrate species)	-
	Forest cover area	Total area covered by forests	km <sup>2</sup>

## 5.2 Data Collection and Pre-processing

The role of data sources in calculating GGDP and evaluating climate mitigation levels is crucial. We collect diverse data from reputable databases (listed in **Table 3**) to ensure accuracy and reliability.

**Table 3: Data sources used in this paper**

Name	Website
Our World in Data	<a href="https://ourworldindata.org/">https://ourworldindata.org/</a>
The World Bank	<a href="https://data.worldbank.org/">https://data.worldbank.org/</a>
Food and Agriculture Organization	<a href="https://www.fao.org/faostat/">https://www.fao.org/faostat/</a>
National Development and Reform Commission	<a href="https://www.ndrc.gov.cn/">https://www.ndrc.gov.cn/</a>
The People's Government of Beijing Municipality	<a href="https://www.beijing.gov.cn/">https://www.beijing.gov.cn/</a>

### 5.2.1 Data Filling

We need to address the missing values in our collected data to ensure the reliability and validity of our findings. When there are gaps with available data both before and after, we use

**mean padding** to fill these missing entries. This method involves calculating the average value of neighboring observations, preserving the overall trend and continuity within the dataset. Additionally, we use **proximity padding** to replace the missing value with that of its nearest neighboring data point when there is no available data before or after it.

### 5.2.2 Data Normalization

By applying these normalization techniques, the data in each column will be transformed to a common scale from 0 to 100, facilitating fair comparisons and analysis. We adopt different normalization methods after analyzing the data carefully.

**For positive indicators, we use min-max normalization.** Each value  $x_i$  subtracts the minimum value:

$$\hat{x}_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \times 100, \quad (5)$$

where  $\hat{x}_i$  is the normalized value of the data point  $x_i$ ,  $x_{min}$  is the minimum value of the  $i$ -th indicator, and  $x_{max}$  is the maximum value of the  $i$ -th indicator.

**For negative indicators, we use reverse min-max normalization.** Each value  $x_i$  is subtracted from the maximum value:

$$\hat{x}_i = \frac{x_{max} - x_i}{x_{max} - x_{min}} \times 100. \quad (6)$$

## 5.3 AHP-CRITIC for Weight Calculation

We choose AHP-CRITIC <sup>[10]</sup> to calculate the weights of secondary indicators. We can capture the relative importance of criteria (AHP) and consider the inter-criteria correlations (CRITIC). This combination of objective data and expert opinions provides a well-rounded perspective for evaluating complex issues of the climate crisis.

### 5.3.1 AHP

The Analytic Hierarchy Process (AHP) is a decision-making method that prioritizes and evaluates alternatives based on multiple criteria. To determine the relative importance of each secondary indicator, we need to compare their influence under the climate crisis.

**Step 1: Establish the decision hierarchy.** Our primary objective is to determine the extent to which each secondary indicator is impacted by the climate crisis.

**Step 2: Pairwise comparisons.** Compare each secondary indicator with every other secondary indicator in terms of their relative importance. A numerical scale is used to derive comparison values.

**Step 3: Create the pairwise comparison matrix.** Construct a matrix representing the pairwise comparisons. The matrix is usually square and symmetric.

**Step 4: Calculate the priority weights.** Determine the priority weights of secondary indicators by computing the geometric mean or eigenvector method based on the pairwise comparison matrix. The weight of the  $i$ -th indicator is

$$\omega_i = \frac{\prod_{j=1}^9 a_{ij}^{1/9}}{\sum_{i=1}^9 \left( \prod_{j=1}^9 a_{ij}^{1/9} \right)}, \quad (7)$$

where  $\omega_i$  is the priority weight of the indicator  $i$ , and  $a_{ij}$  is the pairwise comparison value between elements. From this, we obtain  $\omega_{AHP}$  of nine indicators.

### 5.3.2 CRITIC

The CRITIC (CRiteria Importance Through Intercriteria Correlation) method is used for multi-criteria decision-making. It considers the inter-criteria correlations to determine the weights of the secondary indicators. The weights are calculated using the relationships between the secondary indicators themselves, rather than relying solely on the decision-maker's subjective judgments. The CRITIC weight is calculated by

$$\omega_i = \frac{1}{9} \sum_{j=1}^9 \frac{r_{ij}}{\sum_{i=1}^9 r_{ij}}, \quad (8)$$

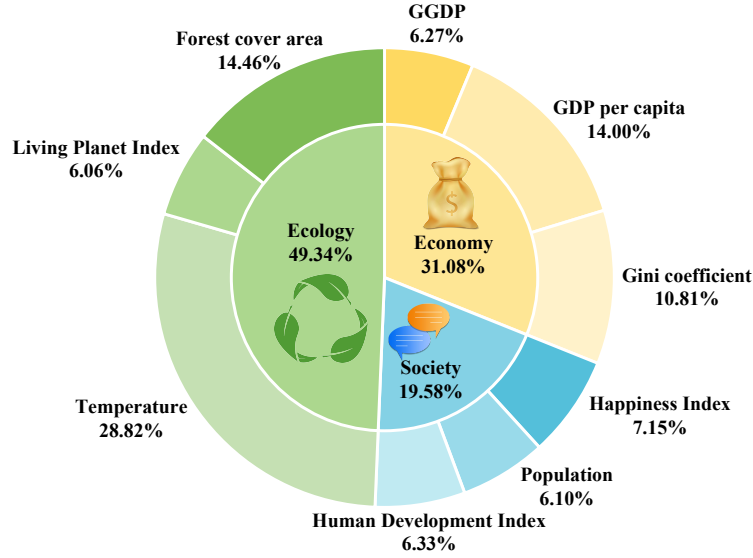
where  $\omega_i$  is the weight of the indicator, and  $r_{ij}$  represents the elements of the normalized correlation matrix. From this, we obtain  $\omega_{CRITIC}$  of nine indicators.

### 5.3.3 AHP-CRITIC Weights Combination

We calculate the weights of primary indicators by AHP, and the weights of secondary indicators by AHP-CRITIC. The combination of indicator weights takes into account both expert knowledge and actual climate impact indicators. Consequently, the derived index weights exhibit a significantly enhanced level of realism<sup>[11]</sup>. The combination weight  $\omega_i$  is calculated by

$$\left\{ \begin{array}{l} \omega_i = \frac{\omega_i'}{\sum_{i=1}^9 \omega_i'} \\ \omega_i' = \sqrt{\frac{\omega_{AHP_i}^2 + \omega_{CRITIC_i}^2}{2}}, i = 1, 2, \dots, 9. \end{array} \right. \quad (9)$$

The weight of each indicator is shown in **Figure 7**. Ecology holds a significant weight of nearly 50% among the primary indicators, while society accounts for less than 20%. This emphasizes the paramount importance of ecology in climate mitigation efforts. Additionally, temperature exhibits the highest weight at 28.82% among the nine secondary indicators. This aligns with common knowledge, as global warming remains a central concern of the climate crisis. Therefore, our assigned weights are rational.



**Figure 7: Weights of secondary indicators**

## 5.4 Result Analysis

To assess the impacts of global climate mitigation, we propose the Climate Mitigation Index (CMI), which ranges from 0 to 100. A higher value indicates more substantial climate mitigation effects. Subsequently, we forecast the global CMI for the next five years under the assumption of implementing GGDP.

### 5.4.1 Climate Mitigation Index

Based on the AHP-CRITIC model, we obtain the weights of secondary indicators. Then the CMI is calculated by

$$CMI = \sum_{i=1}^9 \omega_i \hat{x}_i, \quad (10)$$

where  $\omega_i$  is the weight of  $i$ -th indicator,  $\hat{x}_i$  is the normalized data.

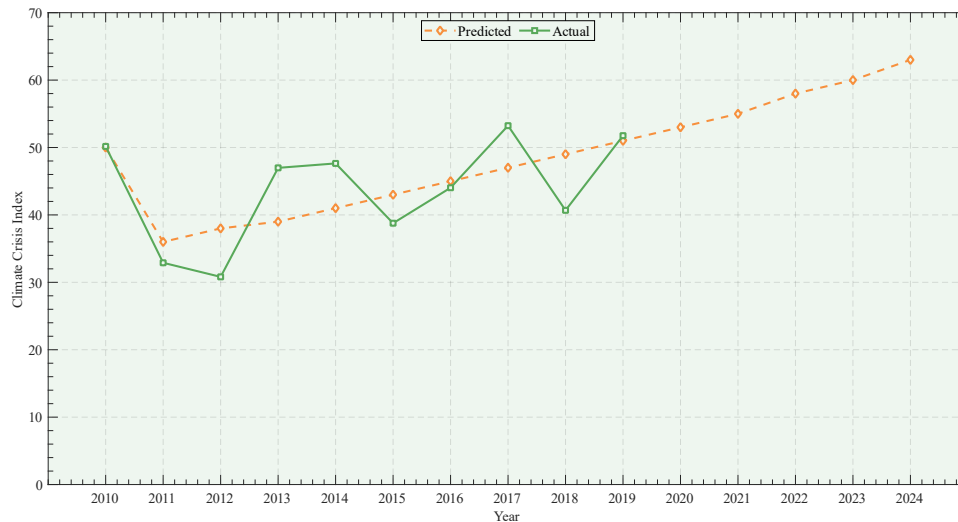
### 5.4.2 GM(1,1)

The GM(1,1) model, also known as the Grey-Markov Model, is a forecasting technique employed for analyzing and predicting future values of a time series. In this study, we utilize data from 2010 to 2019 to forecast the future trend of CMI over five years. Given the limited amount of available data, GM(1,1) proves to be an appropriate approach.

$$\hat{x}(k+1) = (x^{(1)}(1) - \frac{b}{a})e^{(-ak)}(1 - e^a) + \frac{b}{a}, \quad (11)$$

where  $\hat{x}(k+1)$  represents the predicted value of the time series at the time  $(k+1)$ ,  $x^{(1)}(1)$  is the initial value of the time series,  $k$  is the time index,  $a$  is the coefficient of the exponential function, and  $b$  is the coefficient of the accumulated generating operation.

### 5.4.3 Prediction Result



**Figure 8: Prediction Result of CMI**

As depicted in **Figure 8**, the green line represents the observed CMI, while the orange line represents the predicted CMI. From 2010 to 2019, there were fluctuations and an overall increase in the observed CMI, whereas the predicted values exhibited a stable upward trend. Consequently, it can be inferred that climate mitigation efforts will continue to enhance over time, thereby effectively reducing the impact of the climate crisis. The analysis shows that **the impacts of global climate mitigation can be measured based on selected GGDP.**

## 6 Pros and Cons of GGDP

In the previous section, we defined the CMI as a metric for global climate mitigation impacts derived from GGDP. The GGDP shows promise in tackling the climate crisis. Nevertheless, because GGDP is a recent concept, nations will face substantial challenges in implementing it due to the required adjustment period. This section analyzes both the advantages and disadvantages of implementing GGDP from both short-term and long-term aspects.

### 6.1 Positive and Negative Impacts

Based on our AHP-CRITIC evaluation model, the global impacts of climate mitigation are chiefly reflected by nine secondary indicators. If we substitute GDP with GGDP, the secondary indicators will exhibit varying changes over time. We employ GM(1,1) to forecast the values of the nine secondary indicators over the next twenty years. Then we categorize these indicators into those positively impacted and those negatively impacted, from both short-term (next ten years) and long-term (next twenty years) perspectives.

#### 6.1.1 Short-term Impacts

Over 10 years following the adoption of GGDP, the consumption of human-friendly resources such as wood and fossil fuels is expected to decrease in the short term due to policy incentives. Consequently, the ecology is anticipated to experience gradual improvement.

Drawing from literature and rational assumptions, we project a 1% increase in forest area, a 3% rise in the Living Planet Index, and a 0.01% decrease in temperature. In the calculation of GGDP, we assume that resource consumption will decrease by 10%, the recovery rate will increase by 10%, and the costs of processing will decrease by 10%.

Meanwhile, the consumption of relative natural resources will decrease, resulting in a sharp decline in output for certain industries. This reduction in industrial output could potentially lead to a decrease in GDP per capita by 3%, impacting the living quality of individuals to some extent. Additionally, it is expected that not all individuals will be in favor of GGDP policies—therefore, we anticipate a decrease in the Happiness Index by 2% and the Human Development Index by 1%. Considering the decreased living quality, it is projected that the growth of popularity will be slower, leading to a larger rich-poor gap.

**Table 4: Short-term impacts on indicators**

Indicator	Impact	Symbol
GGDP	positive	$P_{11}$
GDP per capita	negative	$N_{11}$
Gini Coefficient	negative	$N_{12}$
Happiness Index	negative	$N_{13}$
Population	negative	$N_{14}$
Human Development Index	negative	$N_{15}$
Temperature	positive	$P_{12}$
Living Planet Index	positive	$P_{13}$
Forest cover area	positive	$P_{14}$

**Table 4** explains the short-term positive and negative impacts on indicators. Four indicators are positively influenced by GGDP, while five indicators bear a negative impact. Subsequently, we compute the Short-term Positive Index (SPI) by

$$SPI = \sum_{i=1}^5 \omega_{1i} P_{1i}, \quad (12)$$

where  $\omega_{1i}$  is the weight of  $i$ -th indicator positively influenced by GGDP in the short term,  $P_{1i}$  is the normalized indicator.

Similarly, we calculate the Short-term Negative Index (SNI) by

$$SNI = \sum_{j=1}^4 \omega_{1j} N_{1j}, \quad (13)$$

where  $\omega_{1j}$  is the weight of  $j$ -th indicator negatively influenced by GGDP in the short term,  $N_{1j}$  is the normalized indicator.

### 6.1.2 Long-term Impacts

Over a 20-year adoption period, GGDP is anticipated to lead to a more favorable living environment, fostering increased recognition of its benefits. Additionally, the development of

renewable technology is expected to be bolstered. Moreover, the implementation of environmental protection policies is projected to contribute to a gradual enhancement of human well-being and development.

Consequently, we anticipate a 5% increase in the Happiness Index and a 6% increase in the Human Development Index. Additionally, population growth is predicted to accelerate, while the rich-poor gap is expected to show mild signs of reduction.

**Table 5: Long-term impacts on indicators**

Indicator	Impact	Symbol
GGDP	positive	$P_{21}$
GDP per capita	negative	$N_{21}$
Gini Coefficient	negative	$N_{22}$
Happiness Index	positive	$P_{22}$
Population	positive	$P_{23}$
Human Development Index	positive	$P_{24}$
Temperature	positive	$P_{25}$
Living Planet Index	positive	$P_{26}$
Forest cover area	positive	$P_{27}$

**Table 5** explains the long-term positive and negative impacts on indicators. Seven indicators are positively influenced by GGDP, but only two indicators still bear a negative impact. Subsequently, we compute the Long-term Positive Index (LPI) by

$$LPI = \sum_{i=1}^7 \omega_{2i} P_{2i}, \quad (14)$$

where  $\omega_{2i}$  is the weight of  $i$ -th indicator positively influenced by GGDP in the long term,  $P_{2i}$  is the normalized indicator.

Similarly, we calculate the Long-term Negative Index (LNI) by

$$LNI = \sum_{j=1}^2 \omega_{2j} N_{2j}, \quad (15)$$

where  $\omega_{2j}$  is the weight of  $j$ -th indicator negatively influenced by GGDP in the long term,  $N_{2j}$  is the normalized indicator.

## 6.2 Result Analysis

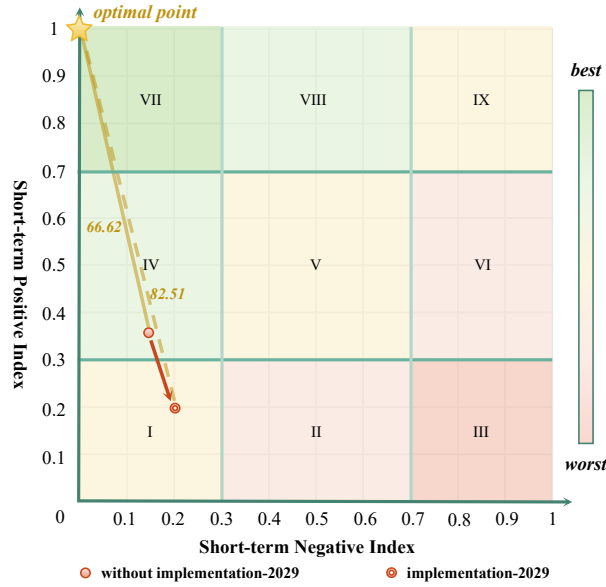
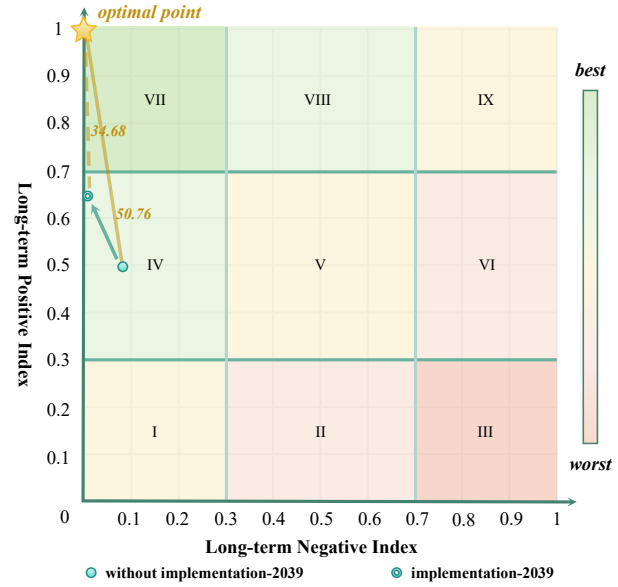
We use the GE matrix <sup>[12]</sup> to analyze the potential benefits and drawbacks of GGDP. The GE matrix, also recognized as the McKinsey matrix, is a strategic tool utilized to visually compare the potential benefits and drawbacks of a set of factors. This framework helps evaluate and prioritize different indicators based on their relative importance and impact on overall performance. By using this approach, we can assess and position climate mitigation within this grid, providing a comprehensive understanding of its significance compared to other key factors.

**Table 6: Index threshold value**

Positive Index	Level	Negative Index	Level
[0, 0.3)	Low	[0, 0.3)	Low
[0.3, 0.7)	Medium	[0.3, 0.7)	Medium
[0.7, 1]	High	[0.7, 1]	High

We categorize the positive and negative impacts into three levels: Low, Medium, and High.

**Table 6** displays the threshold value for each level.

**Figure 9: GE matrix in 2029****Figure 10: GE matrix in 2039**

**Figure 9** and **Figure 10** illustrate the short-term and long-term impacts of GGDP, respectively. The optimal point, located at (0,1), signifies a scenario where negative impacts are nonexistent, and positive impacts are maximized. The VII is the optimal area. While achieving the ideal situation is unattainable due to objective constraints, continuous efforts can bring us closer to this ideal. We also calculate the distance score to the optimal point by

$$\begin{cases} score_{short\_term} = \sqrt{(SNI - 0)^2 + (SPI - 1)^2} \times 100 \\ score_{long\_term} = \sqrt{(LNI - 0)^2 + (LPI - 1)^2} \times 100, \end{cases} \quad (16)$$

where  $score_{short\_term}$  and  $score_{long\_term}$  range from 0 to 141. A higher score indicates a greater distance from the optimal point.

**Figure 9** depicts the short-term impact of GGDP. After the initial decade, the score is projected to increase to 82.51 if we replace GDP with GGDP, in comparison to 66.62 if no action is taken. This suggests that in the short term, the drawbacks of replacement outweigh the benefits. The endeavor to alter the current state will impede climate mitigation efforts within the next ten years. This adjustment period is necessary as nations require time to adapt their industries and societal patterns. Furthermore, some individuals oppose GGDP, necessitating time to adjust their perceptions.



In **Figure 10**, the long-term impact of GGDP is presented. Following two decades, the score is anticipated to decrease to 34.68 if we replace GDP with GGDP, as opposed to 50.76 if no action is taken. This suggests that in the long term, the benefits will gradually outweigh the drawbacks. Nations will progressively embrace GGDP and strive to enhance their GGDP. Consequently, the quality of life will improve, given the advancements in pollution processing technology. Furthermore, people's well-being is expected to see improvements.

In conclusion, although the short-term impacts of GGDP may present some negatives, the ensuing 20 years are predicted to yield substantial benefits. Therefore, transitioning to GGDP on a global scale is deemed worthwhile to foster the development of future generations.

## 7 Case Study of India

As regional differences exist in GGDP implementation, further discussion on the switch in a specific nation is necessary. Developing countries consistently encounter the dilemma between natural resource exploitation and environmental protection, requiring them to strike a balance between development and sustainability. We select India as the research objective, offering several potential strategies to enhance GGDP and analyzing the resulting consequences. The example data we use to calculate GGDP in 2019 can be found in **Table 7**.

**Table 7: Data of India in 2019**

Variable	Value	Unit
GDP	2,835,606,256,616	dollar
Timber area	668,400	Hectare
Total timber price	41,720	dollar
Timber recovery rate	0.5475	-
Freshwater withdrawals	647,500,000,000	billion cubic meters
Water recovery rate	0.23	-
Energy consumption	9,310.841	TWh
Total energy price	10,000,000	dollar
Polluted water	148,925,000,000	ton
Water process cost per billion cubic meters	0.2	dollar
Plastic waste	16,049,334	ton
Plastic process cost per billion cubic meters	265	dollar
Polluted air (carbon dioxide emission)	2,612,888,000	million ton
Air process cost per billion cubic meters	50	dollar
GGDP	2,630,373,004,386	dollar
Share of GGDP	0.9276	-

The data illustrates India's economic standing, natural resource usage, and environmental impact. India's GDP and GGDP signify the economic output and a more comprehensive environmental cost-inclusive measure, respectively. With substantial freshwater withdrawals,

significant plastic waste generation, and polluted water levels, India faces prominent environmental challenges. Additionally, the country's energy consumption underscores its significant energy needs. Addressing these factors is crucial for sustainable development, effective resource management, and mitigating environmental impacts for India's future growth.

## 7.1 Shift Impact Model

We must maintain a balance between economic and sustainable development. A nation's economic status is objectively reflected by GDP. The formula for GDP using the expenditure approach is

$$GDP = C + I + G + (X - M), \quad (17)$$

where  $C$  is consumption expenditure,  $I$  is investment expenditure,  $G$  is government expenditure,  $X$  is exports, and  $M$  is imports. Likewise, the ability to support future generations can be measured by environmental benefits  $E$ .

The change in GDP per capita can be determined by  $\Delta GDP$ . The change in environmental benefits can be measured by altered environmental benefits  $\Delta E$ , including saved natural resource value, recycled waste, and pollution processing. Based on our previous analysis, GGDP implementation will decrease GDP to some extent, but provide environmental benefits in return. Thus, we can calculate the development ratio  $\rho$  to measure the validity of interventions by

$$\rho = - \frac{\Delta GDP}{\Delta E}, \quad (18)$$

where  $\rho < 1$  indicates that India's environmental benefit surpasses the economic cost, thereby the intervention strategies are valid;  $\rho \geq 1$  signifies that the economic cost of implementing GGDP outweighs the environmental benefit, thus intervention strategies are invalid.

## 7.2 Potential Strategies and Impacts

We calculate GGDP by subtracting the environmental cost, encompassing natural resource consumption, waste recovery, and pollution, from the GDP. Accordingly, we propose three targeted strategies corresponding to each aspect.

### 7.2.1 Strategy I: Conserve natural resources

Reducing natural resource consumption is beneficial for enhancing GGDP. Raising awareness through national conservation can decrease individual resource demand. This, in turn, reduces supply and the number of products produced from the consumption of natural resources, thereby diminishing the overall value created in the process. The reduced GDP can be calculated by

$$\Delta GDP_1 = -r \sum_{i=1}^3 C_i V_i, \quad (19)$$

where  $r$  is the policy support ratio ranging from 0 to 1,  $i$  is the type of resource (1 is water resource, 2 is energy resource, and 3 is timber resource),  $C_i$  is the annual consumption volume

of resource  $i$ , and  $V_i$  is the estimated price of resource  $i$  per unit volume. In this scenario, the reduced GDP can be entirely transformed into an environmental benefit, so we have  $\Delta E_1 = -\Delta GDP_1$ .

### 7.2.2 Strategy II: Enhance the recovery rate for resource waste

Over the last five years, India had a plastic waste recovery rate of only 15 percent, indicating ample room for improvement <sup>[1]</sup>. Enhancing the recovery rate of waste enables more efficient resource utilization and results in cost savings. According to GDP calculation, new commodity values are generated through the recycling of water, energy, and wood resources. The increased GDP is

$$\Delta GDP_2 = r \sum_{i=1}^3 C_i V_i \beta_i, \quad (20)$$

where  $C_i V_i \beta_i$  represents the price of recycled waste of resources  $i$ . Moreover, recycling makes a positive contribution to the environment, thereby increasing the overall environmental benefits. We have

$$\Delta E_2 = r W_r T_r, \quad (21)$$

where  $W_r$  is the weight of recyclable waste,  $T_r$  is the price of recyclable waste per ton.

### 7.2.3 Strategy III: Improve the technology for pollutant processing

As a result of implementing the GGDP, governments are improving their pollution processing technology to reduce the cost of processing pollutants. This increase in investment in relevant equipment also boosts industries' revenue and GDP. We have

$$\Delta GDP_3 = 0.3 r^3 GDP, \quad (22)$$

where  $r^2 GDP$  is the investment in pollution processing industries, is allocated to improving equipment, and  $r$  of the equipment investment contributes to increased GDP. Additionally, this strategy can reduce pollution and cut costs. We have

$$\Delta E_3 = r W_u T_u, \quad (23)$$

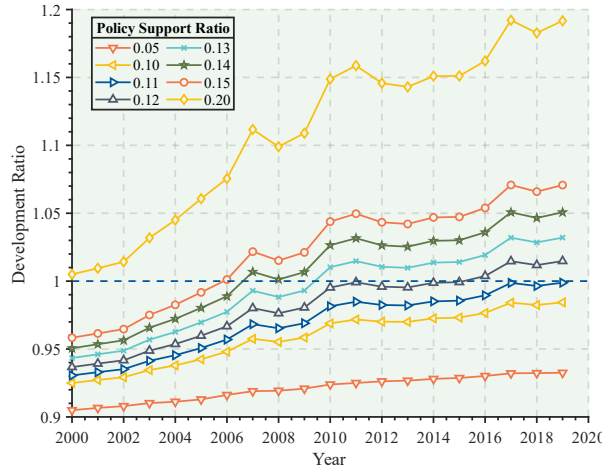
where  $W_u$  is the weight of unrecyclable waste,  $T_u$  is the price of unrecyclable waste per ton.

## 7.3 Result Analysis

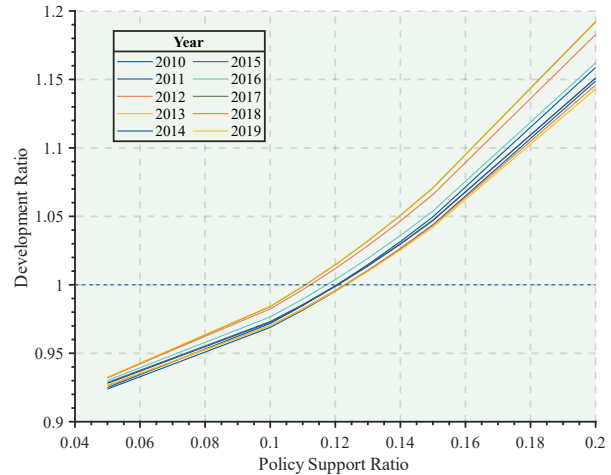
After analyzing the effects of three strategies, we have

$$\rho = - \frac{\Delta GDP_1 + \Delta GDP_2 + \Delta GDP_3}{\Delta E_1 + \Delta E_2 + \Delta E_3}. \quad (24)$$

The  $\rho$  under  $r$  from 0.05 to 0.20 in the years 2010 to 2019 are depicted in **Figure 10** and **Figure 11**. A  $\rho$  less than 1 indicates the strategies are valid and can bring more environmental payback than implementing costs. The Indian government could strategically adapt its policy support over time, aligning it with evolving environment and changing economic status.



**Figure 11: Development Ratio from 2000 to 2019**



**Figure 12: Development Ratio by Policy Support Ratio**

**Figure 11** illustrates  $\rho$  for each year across eight different  $r$ . From 2000 to 2019, if  $r$  remains below 0.11, and the decrease in GDP resulting from the ecological-friendly policies can be balanced by the value of newly generated natural resources. Conversely, excessive  $r$  leads to a GDP reduction that is not offset by the value of natural resources created through ecological-friendly policies. In cases where the reduction in GDP aligns with the compensation from created environmental resources, the GGDP implementation is gradually scaled back over time.

Therefore, in India, when  $r$  is below 0.1, the collective net accumulation of the current economic development loss in India and the augmented support for future generations is positive. However, if India adopts  $r$  exceeding 0.1, although it will amass more environmental resource wealth for future generations, the increase will be insufficient to offset the GDP loss, resulting in a negative combined net wealth value.

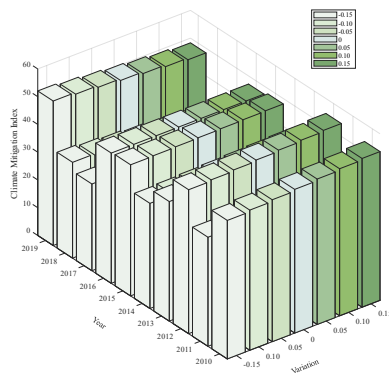
In **Figure 12**, we depict the evolution of  $\rho$  with increasing  $r$ . Assuming a development ratio of 1 corresponds to a policy support proportion of  $\rho_b$  for different years. Over time, as the years progress, the value of  $\rho_b$  diminishes, needing a gradual reduction in policy support by year to prevent reduced GDP from failing to offset the increase in environmental resource value, a consequence of the implementation ratio exceeding  $a$ . In 2019, the value of  $\rho_a$  is 0.11, thereby suggesting that moving forward, the value of  $\rho_a$  must not surpass 0.10 and will continue to decrease over time.

Considering India's economic and political status, along with the yearly changes, we conclude that **implementing GGDP is crucial for accumulating integrated values for India**. Over time, there should be a gradual reduction in India's policy support. This reduction is warranted because the pollution processing equipment and green industries will be advanced, along with increased national conservation awareness. Consequently, this reduction in policy support can continue to realize comprehensive value in society and create more tangible value for future generations.

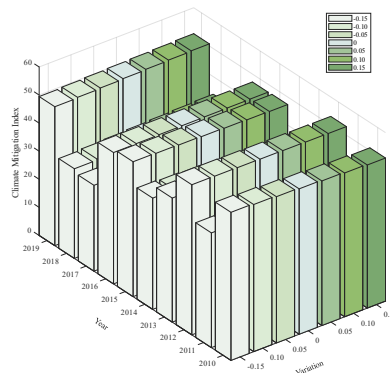
## 8 Sensitivity Analysis

In the AHP-CRITIC model, the weights established by experts inherently contain a subjective element. To guarantee the stability of the model, we specifically perform a sensitivity analysis on these AHP weights. This enables us to assess the impact of variations in these weights on the model's outcomes, ensuring its robustness and reliability.

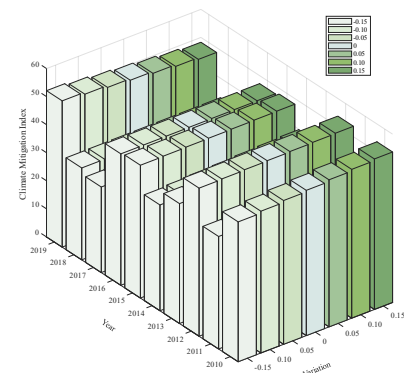
Notably, the forest cover area, human development data coefficient, and Gini coefficient, which collectively hold significant influence among the primary indicators, were specifically chosen for this analysis. We decided to adjust their weights within a range of -0.15 to 0.15, employing increments of 0.05 for each of the three secondary indicators. Subsequently, we calculate the CMI for the years 2010 to 2019 following each weight modification. The resulting data is then visualized through three distinct year-CMI histograms, as displayed in **Figure 13**, **Figure 14**, and **Figure 15**.



**Figure 13: Vary Gini Coefficient**



**Figure 14: Vary Human Development Index**



**Figure 15: Vary forest cover area**

The three figures reveal that as the weights of the Gini Coefficient, HDI, and forest cover area increase, the CMI remains stable, maintaining the overall original order of CMI values across different years. However, in the case of the Gini Coefficient and forest cover area in 2019, an intersection emerges with the CMI values of 2018 and 2017, altering the original order. This signals an increased contribution of the Gini coefficient and forest cover area to the 2019 CMI, indicating amplified societal differentiation and a widening wealth gap.

In light of this, it becomes imperative to consider appropriate measures. The implementation of GGDP and proactive environmentally friendly actions are required to enhance the GGDP. These steps are essential to address the increasing differentiation within society and bridge the widening wealth gap.

Nevertheless, overall, the CMI index exhibits fluctuating growth, suggesting an inclination toward environmental improvement amidst the climate crisis. The sensitivity analysis confirms the robust stability of our model.

## 9 Model Evaluation and Further Discussion

### 9.1 Strengths

- The selected evaluation system indicators are objective, comprehensive, and scientific. We referred to a wide range of literature, upon which we made the necessary changes to enhance the calculation of GGDP.
- We apply proper interpolation and normalization methods for positive and negative indicators.
- We apply AHP-CRITIC to calculate the weights of the indicators in the evaluation system and employ the integrated weight normalization formula creatively. Our weights are thus more scientific and reasonable.
- We introduce development ratios and specific formulas to quantitatively evaluate policy validity in economic growth and future generations support.

### 9.2 Weaknesses

- We assume all countries would actively participate in improving GGDP without considering the resistance from some countries. This oversight may lead to deviations between the actual conditions and our analysis.
- We ignore global and sudden social or natural events. This may introduce errors in our evaluation model.

### 9.3 Further Discussion

- In our impact analysis model, we can incorporate regional effects, such as the degree of public support, to provide a more comprehensive assessment.
- We can account for unforeseen events and propose corresponding strategies for future development to ensure adaptability and resilience.

## 10 Conclusion

We refined the methods for calculating GGDP, considering natural resource usage, waste recycling, and pollution processing costs, impacting climate mitigation. Using AHP-CRITIC, we determined weights for nine secondary indicators in the economy, society, and ecology from 2010 to 2019. We forecasted a mitigated climate crisis using GM(1,1) for the next five years. Additionally, we assessed GGDP's short and long-term impacts with the GE matrix, concluding its potential for global implementation. Focusing on India, we introduced the Policy Support Ratio and Development Ratio, proposing three intervention strategies and recommending a gradual reduction in government support. Next, we write a non-technical report to Indian leaders to show our findings. Finally, our stable evaluation model passed the sensitivity analysis.

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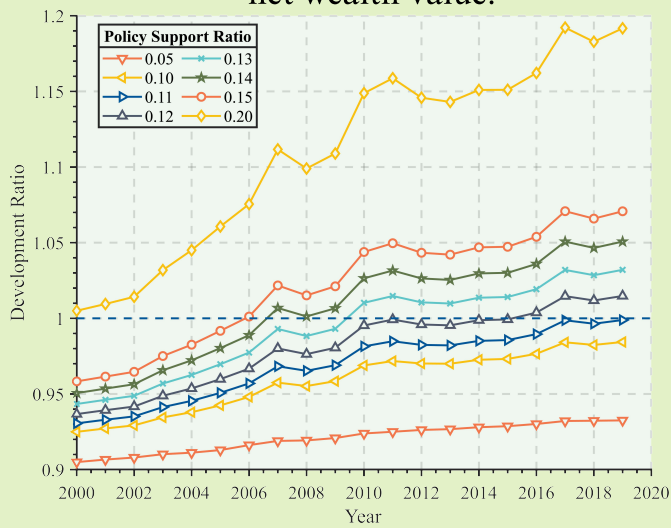
# SHIFT TOWARDS SUPPORTING GGDP

## Analysis The Effect of adapting GGDP



### Analysis Overview

The detailed examination over the period from 2000 to 2019 shown in Figure below demonstrates that with GGDP support ratios below 11%, the decrease in GDP due to environmental protection policies is compensated by the value created through environmental resources. However, overly aggressive policy support ratios could lead to a situation where the decrease in GDP outweighs the environmental gains, resulting in a negative net wealth value.



### Detailed Analysis

For India, a policy support ratio below 10% is currently advisable, as it predicts a positive net accumulation of economic development and support for future generations without compromising the GDP significantly. However, if the policy ratio exceeds 10%, the growth in environmental resource wealth will not offset the GDP loss, leading to a net negative wealth value.

## Policy Recommendation

### Adopt GGDP with Moderate Policy Support

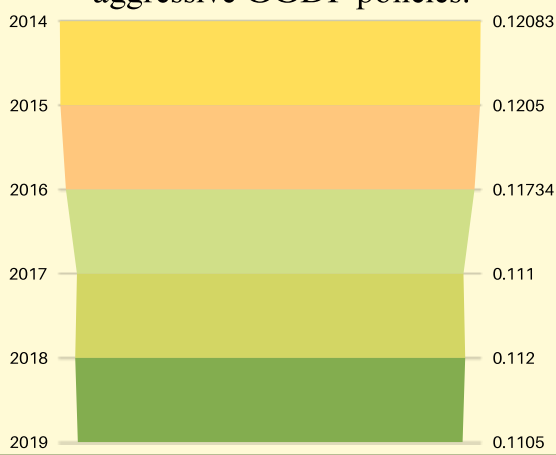
India should proceed with the implementation of GGDP policies, ensuring the policy support ratio remains below 10%. This approach will facilitate a net positive accumulation of comprehensive value, benefiting current and future generations by enhancing environmental resources without severely impacting economic growth.

### Sustainable Development Focus

The shift towards GGDP aligns with global sustainability goals, encouraging the adoption of pollution management technologies and conservation practices. Lowering the GGDP implementation intensity over time will allow India to continue accumulating comprehensive societal value, creating tangible benefits for future generations.

### Gradual Reduction in Policy Support Ratio

As India advances, gradually reducing the GGDP policy support ratio is vital. This ensures the ratio does not surpass the optimal level of 11% in 2019 and is expected to decline as shown by its time trend in Figure below. This adjustment reflects the adoption of advanced pollution control technologies and increased conservation awareness, indicating that India can achieve future economic growth with less reliance on aggressive GGDP policies.





## Report on Use of AI

### OpenAI *ChatGPT*(Nov 5, 2023 version, ChatGPT-4)

Query1: <What impact will advocating green consumption and resource conservation have on India's GDP?>

Output: <1. Investment in Green Technologies and Infrastructure 2. Cost Savings and Efficiency Improvements 3. Cost Savings and Efficiency Improvements>

Query2: <Does the GDP created by producing one kilogram of wood include the value of the wood itself and the labor force involved in the wood production process?>

Output: <Yes, the GDP created by producing one kilogram of wood not only includes the value of the wood itself, but also the total cost and value of labor, energy consumption, processing, transportation, and other related costs during the wood production process. GDP (Gross Domestic Product) measures the market value of all final products and services in a country or region over a certain period of time, therefore, all added value in the production process is accounted for in GDP.>

Query3: <GDP takes into account recycling, and GDP also takes into account recycling. Will there be two recycling values added to GDP?>

Output: <No, not really. When calculating Green GDP (GGDP), the value of recycling is not added twice. Green GDP is an adjustment to traditional GDP, taking into account environmental costs and resource sustainability. The economic value of recycling activities is calculated in GDP at once, while in the calculation of green GDP, the value of these activities is considered as a positive contribution to reducing environmental damage and improving resource efficiency. Therefore, the value of recycling is considered a contribution to environmental protection and resource recycling within the framework of green GDP, rather than double counting.>