Problem Chosen	2023 MCM/ICM Summary Sheet	Team Control Number
F		2309882

Strategies on evaluation and analysis of GGDP: Eco-PACT Model

Summary

As countries around the world are pursuing sustainable development, an environmental friendly method of measuring GDP needs to be proposed, in order to determine the economic health of a country. To solve a series of problems of judging the feasibility of replacing GDP with Green GDP(GGDP), we proposed three models.

For Model 1, the existing studies are carefully investigated and compared, then we establish **a GGDP model based on System of Environmental-Economic Accounting(SEEA)**. According to former researches, we deducted environmental pollution and resource depletion from GDP, and further optimize the model by selecting SEEA as the resource valuation method, and additionally insert two indicators related to abatement. Then we evaluate the pollution cost and resources with three and five indicators, respectively. In addition, we monetize the value using market models, then conclude our GGDP model.

For Model 2, to quantify the change of global climate mitigation, we use the greenhouse gas emissions (after deducting absorption by forests, etc.) to represent climate mitigation. We then apply the **Recurrent Neural Networks(RNN) model** and the **Vecor Autoregression(VAR) model** to identify the relationship between climate mitigation and GGDP indicators. To measure the global impact, we processed the data of four countries each representing a group classified by income, and combine them with coefficients to form the **Linear Impact Model of GGDP(LIMG).**

For Model 3, we innovatively create the **Ecology and Economy impacted Policy and Assessment Model(Eco-PACT)**. Based on LIMG in model 2, we comprehensively considered the cost of switching GDP to GGDP by introducing additional indicators for the economy, policy, and social environment, making a cross-dimension weighting model. Then we normalize the parameters to assure that the Eco-PACT evaluation value is reasonable. Using this model, we calculated the Eco-PACT score of GGDP and GDP policy, and as the former scores higher, the replacement of GGDP with GDP is proved to be effective globally.

The we deal with a more specific situation with our models in the analysis of India, predicting an unsuitable switch from GDP to GGDP. To improve the situation, we proposed the United Nations Subsidy Policy. After the subsidy, the GGDP policy becomes the preferred choice for India.

By constructive analysis of the strengths and weaknesses, we suggest future work and produce a report.

Keywords: Eco-PACT Recurrent Neural Networks(RNN) Vector Autoregression(VAR) Green GDP

Contents

1 Introduction

1.1 Background

Gross Domestic Product (GDP) is one of the most compatible indicators to quantitatively illustrate the economic condition of a country, which is accounted as the total monetary valuation of final products and services[1]. However, GDP fails to cover all the aspects required to evaluate economic health, especially the accounts for natural resources. A country aiming to obtain a high GDP may formulate policies for overproduction, regardless of the potential damage to the environment and future development. The top-ranked countries by GDP per capita has massive carbon emission [Figure 1], causing catastrophic impact on climate balance.

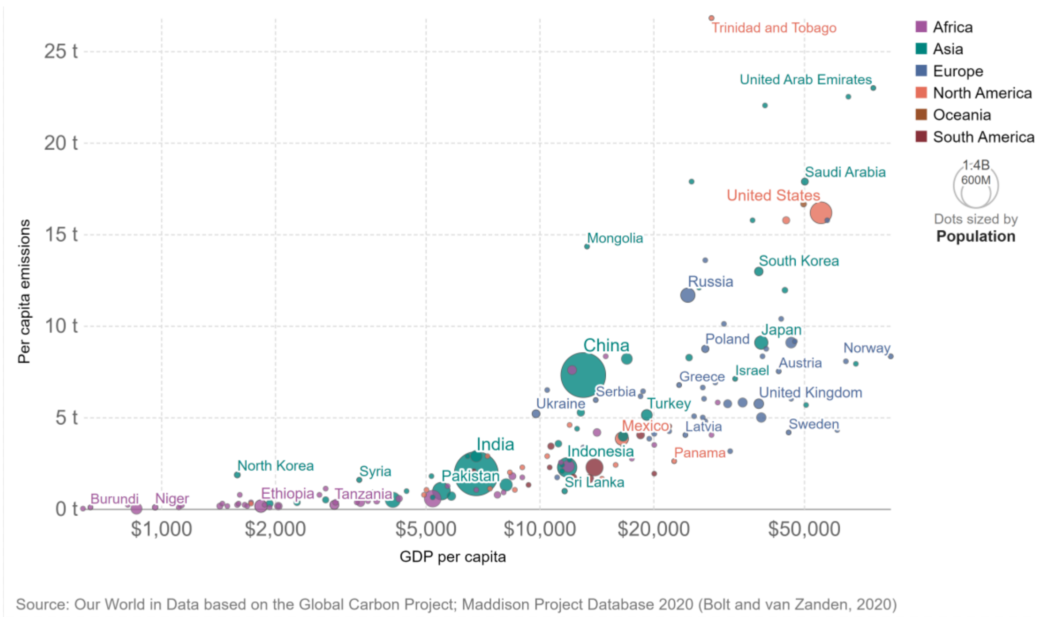

Figure 1: A Fact: CO2 emissions per capita vs GDP per capita

A “Green” GDP(GGDP) model is crucial to measure environmental and sustainable perspectives and factors, providing a more accurate evaluation of economic health and growth. If GDP is switched to GGDP, the country leaders will address more on the impact of production on the environment, and support sustainable development policies. Global ecological and climatic conditions are likely to improve significantly.

However, this switching process could face resistance. Also, the diversity of culture and economic conditions would result in different altitudes towards GGDP. These are the factors that should be noticed and accounted.

Therefore, how to calculate GGDP and decide whether it is applicable to all countries in the world has become an urgent problem to be solved. In this article, we will put forward a model of GGDP, and discuss the feasibility of replacing GDP with it, predicting its impact on climate mitigation and potential development for countries.

1.2 Problem Restatement and Analysis

- **Problem one:** Establish a GGDP model based on existing research, whose impact on improving climate mitigation could be quantitatively measured by equations or models.
- **Problem Two:** Propose a model to evaluate the change of global climate mitigation when GGDP is adopted, that is, to assess the change of climate mitigation indicators with GGDP indicators.
- **Problem Three:** Evaluate the cost of switching to GGDP in the economy, society, etc., and compare with the climate mitigation benefits at a global scale.
- **Problem Four:** Apply the evaluation model in a specific country, and further assess the change based on its economic conditions, and predict the future situation within the adoption of GGDP policy. Make comparisons to the current GDP policy, and give suggestions on whether to accept the switch.
- **Problem Four:** According to the analysis in Problem Four, write a report to the leader of the chosen country on whether to opt for the GGDP model instead of GDP.

1.3 Overview of our work

To avoid complicated description and intuitively reflect our work process, the flow chart is shown as the following figure 2:

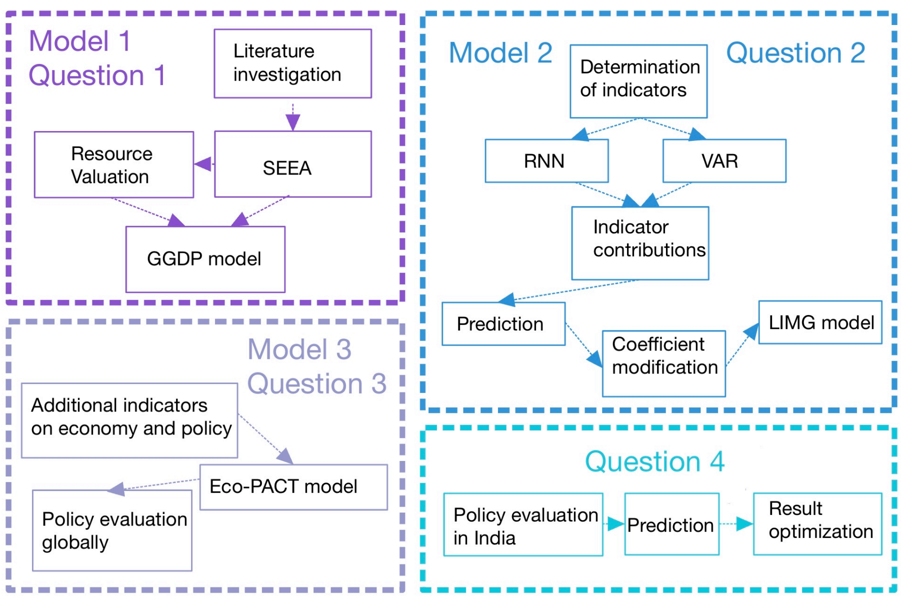

Figure 2: The Framework of Our Work

2 Assumptions and Notations

Assumptions:

- We assume that the selected four countries can each appropriately represent the conditions of its classification.
- We assume the data collected from World Development Indicators is accurate.
- We assume that the indicators in the model can describe the overall economic and environmental situation of the country or region.

Notations:

Symbol	Definition	Abbreviations	Definition
x_i	Evaluation indicator	EPV	Environmental Pollution Value
y	Climate mitigation indicators	RDV	Resource Depletion Value
C_i, p_i, n_i	Classification coefficients	ELV	Environmental Loss Value
α_i	Weighting coefficient	PAC	Pollution Abatement Cost
W	Impact coefficient matrix	WUV	Waste Utilization Value
GGE	Greenhouse Gas Emission	WD,LD,FD,ED,MD	Water,Land,Forest,Energy,Mineral Depletion
CDD	Carbon Dioxide Damage	PED	Particulate Emissions Damage
ER	Employment Rate	EC	GDP growth rate
		ECO,ENV,SOC	Economic,Environmental,Social indicators

Table 1: The list of Notation

3 A GGDP Model Based on System of Environmental-Economic Accounting(SEEA)

3.1 Main Classification of GGDP

Depending on different accounting perspectives, GGDP can be categorized into two types[2].

GGDP-I mainly considers the Value of Environmental Pollution(EPV) and Resource Depletion(RDV).

$GGDP_I = GDP - EPV - RDV$

GGDP-I internalizes the natural environment, which is normally considered external in the market, thus clarifying the importance of resource and environmental costs in the national economic system. However, there are many aspects of ecosystems that deserve attention, and calculations that only account for EP and RD are inadequate. Also, how to quantify the value of natural resources and pollution needs further discussion.

GGDP-II includes the value of natural ecosystem services as environmental benefits.

$GGDP_{II} = GDP + ESI$

$$ESI = Ecosystemservicesvalue - Ecologicalcost$$

Where ESI is short for Ecosystem Services Index, representing the final ecosystem services value. GGDP-II monetizes the service value as an intrinsic feature of natural ecosystems. However, the service value varies from different geography and time, making it hard to be defined owing to the different characteristics of each area. The second barrier is the lack of a mature method to determine the total value of services, which contains not only the aesthetic value, heritage value, and existence value.

Overall, accounting for the upside and downside of these two types of GGDP, **we eventually select GGDP-I as the primary model.** The reasons are as follows.

(a) GGDP-I deducted GDP production that harms the environment, which emphasizes more on the conditions of disrupted ecosystems rather than their dedication to human beings. We believe the pollution to the environment, especially to the air regarding climate mitigation, should be taken into account, which is not in the monetization of GGDP-II.

(b) The GGDP-I has an abundant database that is accessible on official websites. Comparatively speaking, the GGDP-II is newly proposed, resulting in the absence of multilateral data and limited time series data.

(c) The GGDP-II has inconsistent and sophisticated evaluation methods for each ecosystem, making it inconvenient to quantify due to the diversity and variability of ecosystems.

(d) The accounted GGDP-I is apparently lower than GDP, while GGDP-2 is higher. As is found in psychology studies, people care more about losses rather than gains. For policy makers, the lower-than-GDP accounting system could be a wake-up call, pushing them forward with the environmental protection process.

Distinguished from the original GGDP-I, **we have further optimized the model** for practical applications.

(a) We monetized Resource Depletion Value(RDV) and Environmental Pollution Value(EPV) based on the classification of the resources according to the System of Environmental Economic Accounting(SEEA).

(b) We supplemented EPV with Pollution Abatement Cost (PAC), collectively referred to as Environmental Loss Value (ELV).

(c) We added the indicator Waste Utilization Value (WUV) to the equation.

The final GGDP model is

$$GGDP = GDP - RDV - ELV + WUV$$

3.2 System of Environmental-Economic Accounting(SEEA)

To reasonably monetize the cost of natural resource depletion and environmental pollution, we investigate several accounting models, including National Accounting Matrix including Environmental Accounts(NAMEA), European System for the Collection of Economic Information on the Environment(SEIEE), Environmental and Natural Resources Accounting Project(ENRAP) and System Environmental and Economic Accounting(SEEA).

Among them, the SEEA was developed by the United Nations Statistical Office, which took the lead in organizing research and development by national experts, and treats SEEA as a subsidiary framework to SNA(the foundation of GDP)[3]. There is no doubt that it can better adhere to the design ideas of SNA and achieve the best alignment with SNA, which means the GGDP based on SEEA will also have the best connection with GDP, reducing resistance when switching.

In this system, the natural resource account is a full-chain measurement record from the perspective of material circulation. The main focus is to use the physical unit to record the material and energy flows in and out of the economy, along with the material and energy flows within the economy, making it more systematic and comprehensive than the natural resource environmental accounting in the SNA.

Specifically, SEEA-Central Fracture has set up seven groups of natural resource asset accounts based on the definition and classification of various natural resources. These asset accounts contain two types of accounting tables, physical quantity and value, which basically reflect the circulation mode of natural resources in the ecological and economic cycle, that is, ' initial stock - current stock increase - current stock decrease - current physical quantity and price adjustment - final stock '. At the same time, SEEA also systematically accounts the resource management and environmental protection[4].

SEEA puts water resources, energy, minerals, wood, fish, soil, land, pollution and other information in a single measurement system, and specifies measurement methods for each field. Therefore, with SEEA as the theoretical basis, the monetization accounting of natural resource assets can be achieved.

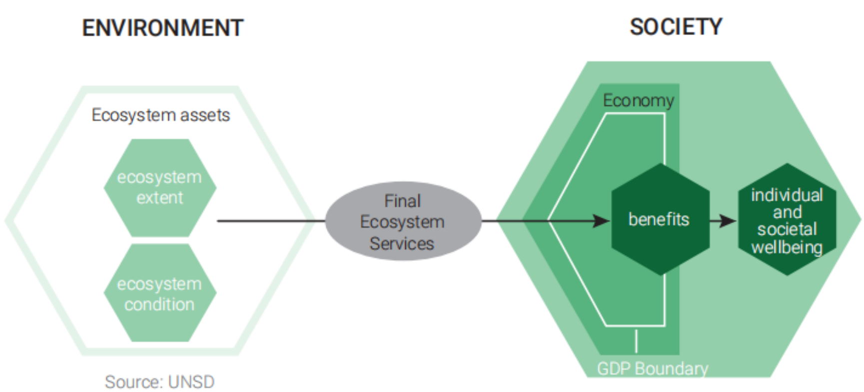

Figure 3: Conceptual framework of ecosystem accounting

3.3 Valuation Study

For resource depletion value(RDV) indicators, according to the SEEA accounting framework system and data availability, we classify natural resources into five categories: water resources, land resources, forest resources, energy resources, and mineral resources. These should be futher valuated[[6]].

For environmental loss value(ELV), we futher considered four indicators: water pollution, particulate emission, carbon dioxide emission and pollution abatement cost (PAC).

For waste utilization value(WUV), we collected information from the official website of different countries.

3.3.1 Water resources valuation

Shadow price model. The model uses constrained optimization methods to estimate the value of water resources. The target value is to maximize the economic benefits and profits of resources. Under the condition that other things remain unchanged, the marginal income of resources is calculated by adjusting the number of unit resources and using the quantitative analysis of resource utilization value. In this case, the price of water is the marginal income.

$$WaterDepletion(WD) = Price_{WD} \cdot (Quantity_{WD}^{initial} - Quantity_{WD}^{terminate})$$

Price of unit water resource:

$$Price_{WD} = F/Q \cdot \alpha$$

Where F is the total output value generated by the producers of water-using industries. In view of the availability of data, the total value of production is used as an approximation. Q is the water consumption. α is the coefficient of willingness-to-pay of consumers.

3.3.2 Land resources valuation

Market comparison method. Based on the principle of substitutability, the market comparison method compares the land to be evaluated with similar plots traded on the market on the evaluation day. According to the differences in land characteristics, the transaction price is modified to estimate the appropriate land price.

$$LandDepletion(LD) = Price_{LD} \cdot (Quantity_{LD}^{initial} - Quantity_{LD}^{terminate})$$

Price of unit land:

$$Price_{LD} = GAP/Area$$

Where GAP stands for Gross Agricultural Product.

3.3.3 Forest resources valuation

Market approach. The market approach refers to the use of market prices to estimate the value of forest resources. The actual price of forest resources traded in the market is considered to be the value of unit forest resource assets. This type of method is only applicable to areas with complete or mature timber markets.

Income approach. The income approach is to estimate the value of forest resources assets by predicting the normal net income of forest resources in the future, selecting the appropriate rate of return on investment, converting it to the evaluation date, and then performing the summation operation.

$$ForestDepletion(FD) = Price_{Timber} \cdot (Quantity^{initial}_{Timber} - Quantity^{terminate}_{Timber})$$

$$+Price_{Woodland} \cdot (Quantity^{initial}_{Woodland} - Quantity^{terminate}_{Woodland})$$

3.3.4 Energy and mineral resources valuation

$$EnergyDepletion(ED) = Price_{ED} \cdot (Quantity^{initial}_{ED} - Quantity^{terminate}_{ED})$$

$$MineralDepletion(MD) = Price_{MD} \cdot (Quantity^{initial}_{MD} - Quantity^{terminate}_{MD})$$

3.4 Conclusion

$$GGDP = GDP - RDV - ELV + WUV \tag{1}$$

$$RDV = WD + LD + FD + ED + MD = \Sigma(Q^{initial} - Q^{terminate}) \cdot P \tag{2}$$

$$ELV = PDV + PA \tag{3}$$

Where Q is the quantity of the indicators, and P is the unit price.

4 GGDP Impact on Global Climate Mitigation

4.1 Determination of indicators

Climate mitigation is defined as those human actions that help to reduce or stabilize the concentration of GHGs in the atmosphere to levels that prevent a dangerous anthropogenic disturbance of the climate system[7]. We use **the alteration of Greenhouse Gas Emissions** (GGE, after deducting absorption by forests, etc.) to identify climate mitigation progress.

In order to measure the global impact, we classify countries into four categories, based on available GDP and an internationally accepted approach, and select one representative country for each classification. That is:

· The United States represents High-income countries

- China represents Upper-middle-income countries
- India represents Lower-middle-income countries
- Afghanistan represents Low-income countries

As analyzed in Section 3, GGDP contains a total of ten indicators in addition to GDP[(1)-(3)]. We performed Principal Component Analysis(PAC) on these indicators and reduce the number of variables to five. The correlation analysis exhibits that the independent variables are not strongly correlated[Figure 4], proving that our choice of indicators is appropriate.

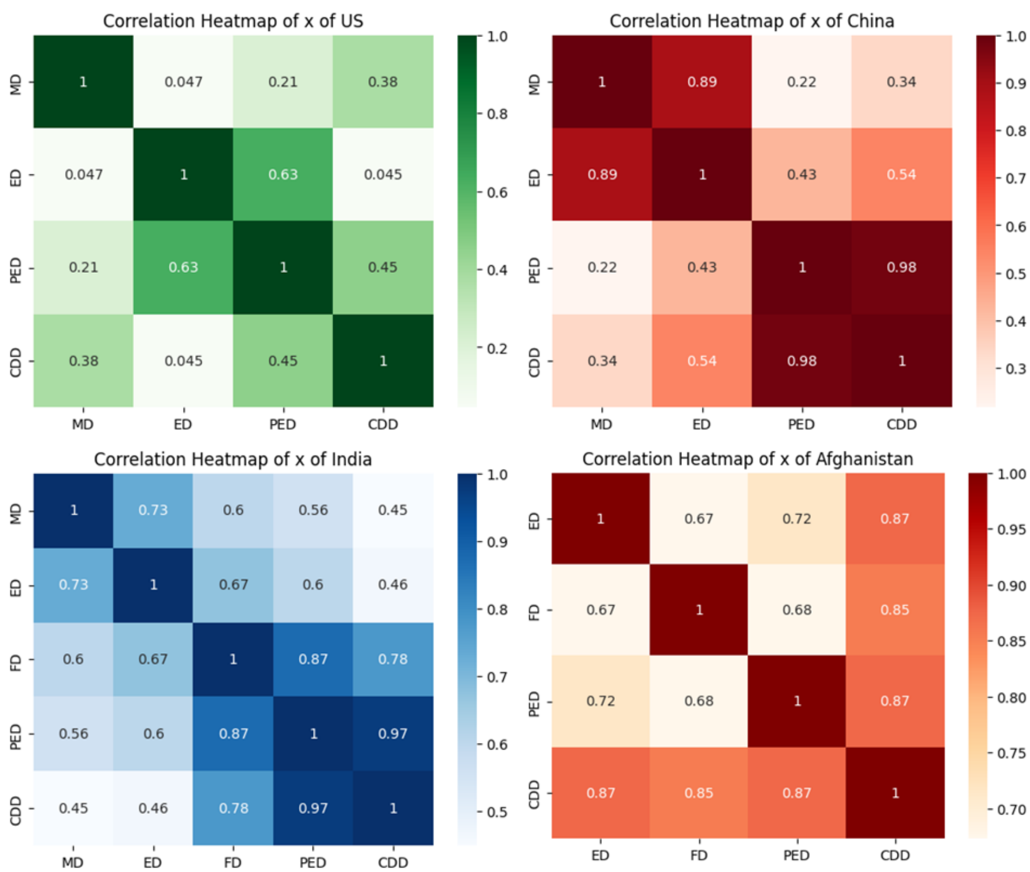

Figure 4: Correlation analysis among indicators

The variables are:

- Forest depletion(FD, current US$): Net forest depletion is calculated as the product of unit resource rents and the excess of roundwood harvest over natural growth.
- Energy depletion(ED, current US$): Energy depletion is the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years). It covers coal, crude oil, and natural gas.

- Mineral depletion(MD, current US$): Mineral depletion is the ratio of the value of the stock of mineral resources to the remaining reserve lifetime (capped at 25 years). It covers tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite, and phosphate.
- Particulate emission damage(PED, current US$): Particulate emissions damage is the damage due to exposure of a country's population to ambient concentrations of particulates measuring less than 2.5 microns in diameter (PM2.5), ambient ozone pollution, and indoor concentrations of PM2.5 in households cooking with solid fuels. Damages are calculated as foregone labor income due to premature death. Estimates of health impacts from the Global Burden of Disease Study 2013 are for 1990, 1995, 2000, 2005, 2010, and 2013. Data for other years have been extrapolated from trends in mortality rates.
- Carbon dioxide damage(CDD, current US$): Cost of damage due to carbon dioxide emissions from fossil fuel use and the manufacture of cement, estimated to be US$40 per ton of CO2 (the unit damage in 2017 US dollars for CO2 emitted in 2020) times the number of tons of CO2 emitted.

Data is obtained from the database: World Development Indicators [5].

Overall, we derived five independent variables (FD, ED, MD, PED, CDD) to indicate GGDP and one dependent variable (GGE) to indicate climate mitigation.

4.2 India: Representing Lower-middle-income countries

4.2.1 Recurrent Neural Networks(RNN) model

We establish a simple RNN model to predict the relationship between the dependent variable GGE and the independent variable. Specifically, we use an RNN model with two LSTM layers, each of which contains 64 units for processing time series data. Then, we pass the output of the LSTM layer to a fully connected layer to predict the GGE values. We use the Adam optimizer to optimize the loss function of the model, and the loss function uses the mean square error as a measure.

·**Establish RNN model**

Algorithm 1: Establish RNN model

```
model=keras.Sequential.()
model.add(layers.LTSM(64, input_shape=(timesteps,data_dim)))
model.add(layers.Dense(64, activation='relu'))
model.add(layers.Dense(1, activation='linear'))
model.compile(optimizer='adam', loss='mean_squared_error') // Adam optimizer
model.fit(X_train, y_train, epochs=10, batch_size=32
```

In this model, we use the independent variables from the past five years as inputs to predict the value of GGE in the next year. This means that the model uses historical data between the independent variables to predict future values of the dependent variable. Due to the internal mechanism of the LSTM layer, the model can capture long-term dependencies in the time series data and can learn nonlinear patterns, which is useful for predicting the relationship.

·Data pre-processing

After the RNN model is built, we need to preprocess the data from the test set into the form of a 3D tensor for input. Here we use the same normalization approach to preprocess the test set. The independent variables are set as x_i, and the GGE variable is set as y.

Algorithm 2: Data pre-processing

```
test_df=df.iloc[train_size:, :]
test_df=(test_df-train_mean)/train_std
Input: x_test,y_test
for i in range(time_steps,test_df.shape[0]) do
    x_test.append(test_df.iloc[i-time_steps:i, :].values)
    y_test.append(test_df.iloc[i-time_steps:i, :].values)
end
Output: np.array(x_test), np.array(y_test)
```

·Predictions

Then, we can use the trained model to make predictions on the test set, and calculate the mean square error (MSE) and mean absolute error (MAE) of the predicted results versus the actual values to evaluate the predictive power of the model.

Algorithm 3: Predictions

```
Input: np.array(x_test), np.array(y_test)
y_pred=model.predict(x_test) // make predictions on the test set
y_pred=(y_pred*train_std[0])+train_mean[0]
y_test=(y_test*train_std[0])+train_mean[0] // inverse normalization to predict the
    result and the true value
MSE=mean_squared_error(y_test, y_pred)
MAE=mean_absolute_error(y_test, y_pred) // calculate MSE and MAE
Output: MSE,MAE
```

The MSE and MAE can be defined as

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

where n is the number of samples, y_i is the actual value, and $\hat{y}_i$ is the predicted value

Output result:
MSE: 113345725.797
MAE: 8764.083

Based on the values of MSE and MAE, we can see that the RNN model does not predict very well and has a large prediction error. Therefore, we may need to further optimize the model or find other methods to establish the relationship between the dependent variable GGE and the independent variables.

4.2.2 Vector Autoregression(VAR) model

We can use the vector autoregression (VAR) model to establish the relationship between the dependent variable y and the independent variable. The VAR model is a multivariate time series analysis method, which can consider the interaction between multiple variables at the same time.

Before using the VAR model, we need to preprocess the data, including the time series stationarity test, differential processing and model order selection. Once we determine the parameters of the VAR model, we can use it to predict the future value of GGE.

Algorithm 4: VAR model

```
Result = sm.tsa.statools.adfuller(data, maxlag=1) // verification of stationarity
if result[0]<result[4]['5%'] then  if time series is stationary
    model=VAR(data)
    Order=model.select_order() // automatic selection of model order
    Output: results.summary()
end
else if time series is not stationary, differential processing is required
    Diff_data+data.diff().dropna()
    Model=VAR(diff_data)
    Order=model.select_order()
    Results=model.fit(maxlags=order)
end
Output: results.summary()
```

From the results, the model fits well overall, with high R^2 values, indicating that the model can explain most of the variation of the dependent variable GGE. Meanwhile, the autocorrelation of the residuals is low, indicating that the model has better captured the dynamic relationships among the independent variables.

By examining the coefficients of the respective variables, we can draw the following conclusions:

Assuming that the lag order of all independent variables is $p = 2$, the model expression is:

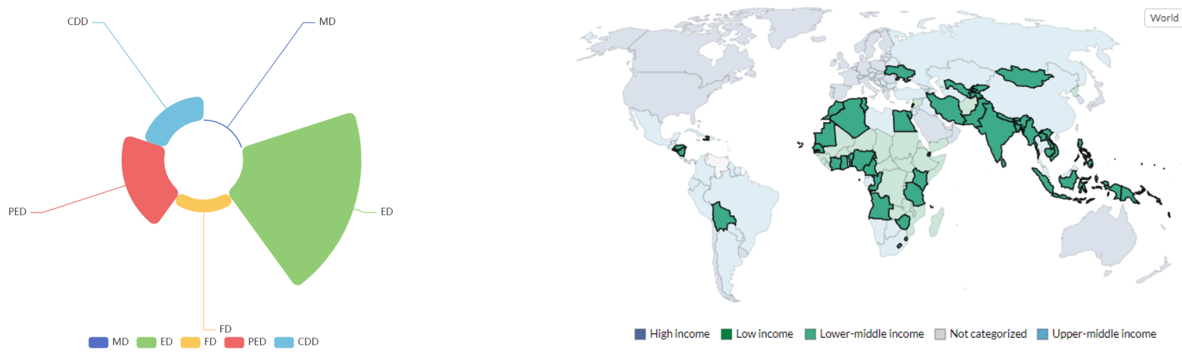

Figure 5: India: The contribution of indicators to GGE

$$y_t = 37709.47 + 0.00071x_{1,t-1} + 0.0757x_{2,t-1} + 0.0082x_{3,t-1} + 0.0273x_{4,t-1} - 0.0155x_{5,t-1}$$
$$-0.00012y_{t-1}+0.00022x_{1,t-2}-0.0203x_{2,t-2}+0.0021x_{3,t-2}-0.0031x_{4,t-2}-0.0097x_{5,t-2}+0.0059y_{t-2}+\varepsilon_t \tag{4}$$

Where $x_{1,t-1}$ denotes the value of the independent variable x_1 at moment $t-1$, y_{t-1} denotes the value of the dependent variable y at the moment $t-1$, and ε_t denotes the error term, which contains all the effects not explained by the model.$x_1 = MD, x_2 = ED, x_3 = FD, x_4 = PED, x5 = CDD, y = GGE$

In summary, the indicators ED, FD, PED in GGDP have an impact on the lower middle income country represented by India, with FD having a significant impact.

4.3 China: Representing Upper-middle-income countries

4.3.1 RNN model

The MSE of the model is 1.905215^{-10} and the MAE is 1.145868^{-05}

The differences between the model predictions and the true values are relatively small, indicating that the model can better capture the relationship between the dependent variable y and the independent variables.

With the RNN model, we can get the magnitude of the effect of each independent variable on the dependent variable. In this model, we can understand the magnitude of each independent variable's influence on the dependent variable by looking at their weights in the model.

Specifically, we can use the parameters in the model to calculate the contribution of each independent variable to the dependent variable. Suppose the input to the model is a sequence of length seq_length, where $x_1, x_2, ..., x_4$ represent the four independent variables, y is the dependent variable, and the output of the model is $\hat{y}$. For each independent variable x_i, we can calculate its contribution to $\hat{y}$ as

$$frac\partial\hat{y}\partial x_i = \sum_{j=1}^{seq_length} \frac{\partial \hat{y}}{\partial h_j} \frac{\partial h_j}{\partial x_i}$$

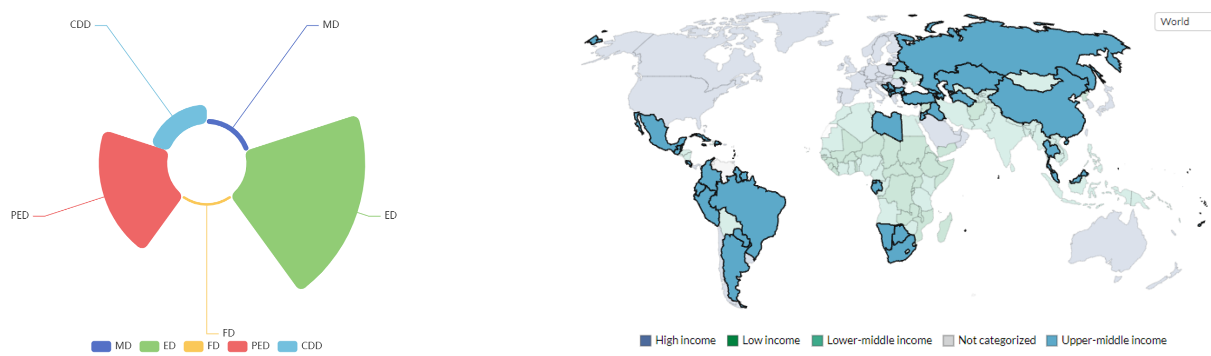

Figure 6: China: The contribution of indicators to GGE

Where h_j is the hidden state of the model at the jth time step of the sequence, and $\frac{\partial \hat{y}}{\partial h_j}$ is the partial derivative of $\hat{y}$ with respect to h_j, which can be calculated by back propagation of the model. $\frac{\partial h_j}{\partial x_i}$ is the partial derivative of h_j with respect to x_i.

The contributions of each independent variable to $\hat{y}$ are calculated as

MD: 0.0175
ED: 0.4125
FD: 0.0063
PED: 0.2375
CDD: 0.0672

To conclude, for the upper middle-income country represented by China, the indicator ED in GGDP contributes the most to the prediction results, followed by PED and CDD, and FD contributes the least to the results.

4.4 US: Representing High-income countries

4.4.1 RNN model

The MSE of the model is 5.111854^{-12} and the MAE is 1.155582^{-06}. The difference between the model prediction and the true value is relatively small, so the relationship can be evaluated by RNN model.

The contributions of each independent variable are calculated as
MD: 0.6545
ED: 0.8008
FD: 0.0883
PED: 0.2584
CDD: 0.4072

To summarize, for the high income country represented by US, the indicator ED and MD in GGDP contributes significantly to GGE results, followed by CDD and PED, and FD contributes the least to

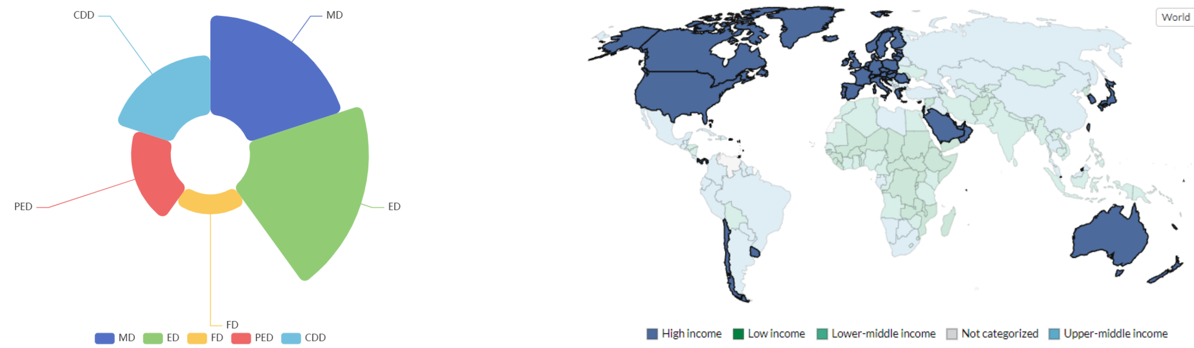

Figure 7: US: The contribution of indicators to GGE

the results.

4.5 Afghanistan: Representing Low-income countries

4.5.1 RNN model

The MSE of the model is 146.3724 and the MAE is 10.6516. The evaluation error is not so ideal, and the results could be combined with the VAR model results.

The contributions of each independent variable are calculated as
MD: 0.0343
ED: -38.83
FD: -0.15
PED: 7.04
CDD: 0.12

It can be seen that the ED contributes the most to the model prediction and is negatively correlated, thus the larger the value of ED, the smaller the model prediction; MD, FD and CDD contribute little to the model prediction and are close to zero; PED contributes more to the model prediction and is positively correlated, therefore the larger the value of PED, the larger the model prediction.

4.5.2 VAR model

The error evaluation of VAR model is $MSE : 2.2611^8$, $MAE : 11709.811$, $RMSE : 15033.057$. As is analyzed, the errors of these evaluation indicators are not very small, which means that the method requires further improving.

Based on the results of the above VAR model, we can determine whether the effect of each variable on the GGE is significant by calculating the t-statistic. That is, assuming a significance level of 0.05, then the effect of the independent variable should correspond to a t-value. When the variable is with an absolute value greater than 1.96, it is considered significant.

According to the results, we can see that the t-statistics are:

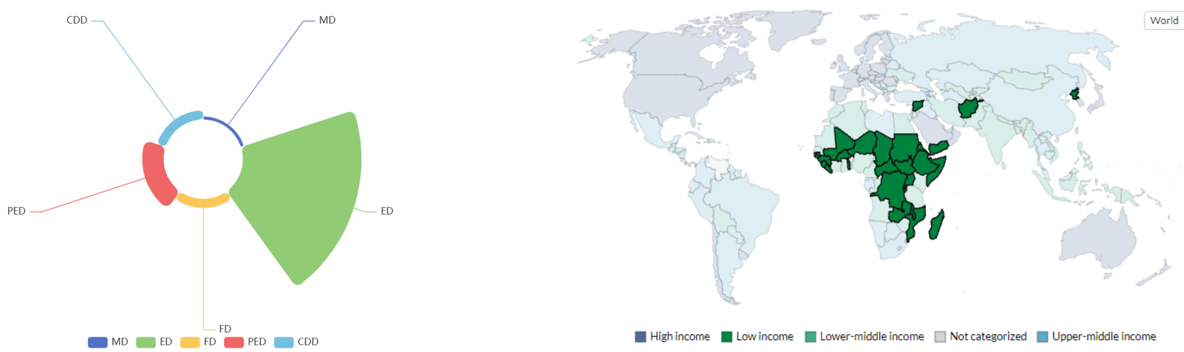

Figure 8: Afghanistan: The contribution of indicators to GGE

MD: 0.0000
ED: -0.1319
FD: -0.4283
PED: 3.5463
CDD: 0.7402

Here only the effect of PED is significant, and the effects of the remaining independent variables are not significant.

Overall, the performance combined of the RNN and VAR models shows that the impact of the PED indicator is most significant in the low-income countries represented by Afghanistan.

4.6 Conclusion by LIMG model

Considering all the representative countries, the Energy Depletion has a great significance on GGE, which in turn affects climate mitigation.

For high-income countries, the Mineral Depletion takes the second percentage, which might result from the rich mineral resources in the US. Additionally, all the indicators in the high-income country analysis are more significant than the other countries. This phenomenon might be owing to the balanced production in all areas for this country classification.

For middle income countries, China and India have similar relative contributions of all the indicators. One thing to differ is that, as the income increases, the impact of Particulate Emission Depletion increases while the Forest Depletion decreases. The reason could be that, with more production comes more particle pollution emmission and more forest damage.

For low-income countries, only the Energy Depletion is of significant importance, based on the fact that these countries lack industrial production

In this section, we use RNN and VAR models to quantify the climate mitigation (indicated by GGE) as a function of five variables, as shown in Equation (4). Combining the situation and number of different country categories, we can synthesize a Linear Impact Model of GGDP(LIMG), demonstrating the impact of each GGDP indicator on global climate mitigation.

$$y = \Sigma_{i=1}^{4} p_i \lambda_{ij} \cdot x_{ij} \tag{5}$$

$$C_i = p_i \cdot n_i / \Sigma_{i=1}^{4} p_i \cdot n_i \tag{6}$$

Where C_i is the classification coefficient. p_i is based on the population percentage of the certain classification, and is added up to 1. n_i is the area of countries of the classification divided by the total area of all countries.

The values of coefficient p_i, n_i and C_i is listed below[Table 2].

Country Classification	High Income	Upper Middle Income	Lower Middle Income	Low Income
p_i	15%	32%	44%	9%
n_i	27%	41%	19%	13%
C_i	0.109	0.352	0.225	0.314

Table 2: List of Country Classification Coefficients

The contribution coefficient λ_{ij} varies with different country classifications and indicators, which are given in corresponding subsections.

The variable x_i represents the indicators MD, ED, FD, PED and CDD. y_i represents GGE.

5 Determine the Upside and Downside of GGDP with Eco-PACT Model

5.1 Introduction of Eco-PACT

Based on the data provided, the global GDP growth rate has been generally positive over the past 25 years, with an average growth rate of approximately 3.8%. However, there have been some fluctuations in the growth rate over the years, with a low of -2.2% in 2009 and a high of 5.5% in 2007.

At the same time, the data shows a continuous increase in greenhouse gas emissions over the years, with the amount of carbon dioxide emitted increasing from 23.79 Gt in 1996 to 36.51 Gt in 2019. This trend is a cause for concern, as it suggests that efforts to reduce greenhouse gas emissions have not been effective enough to prevent further damage to the environment.

In terms of employment rate, the data shows a relatively stable trend over the years, with an average rate of around 62%. This suggests that, despite the economic fluctuations, the global job market has

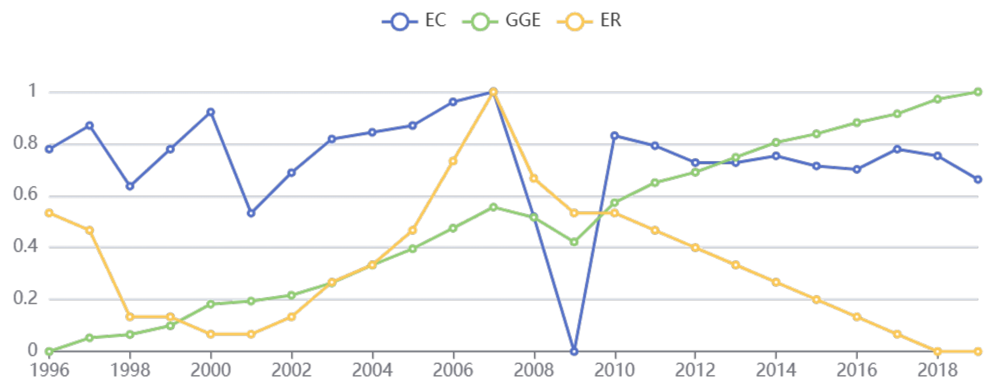

Figure 9: Global GDP growth, greenhouse gas emissions and employment over 25 years

been able to maintain a certain level of stability.

Overall, the data suggests that economic growth and environmental protection are still in conflict with each other, as economic growth has come at the cost of increasing greenhouse gas emissions. This highlights the need for policies and strategies that can balance economic growth with environmental protection.

To solve the problem, **we create the Ecology and Economy impacted Policy and Assessment Model(Eco-PACT)**. The Eco-PACT model can comprehensively consider the economic and environmental impact factors of policies and evaluate the effects of policy implementation.

5.2 Parameters of Eco-PACT

Apart from GGE and previous GGDP indicators, we updated new parameters to analyze the economy, policy, and social environment. These are:

· EC: GDP growth rate

· ER: Employment rate

· ECO: Economic indicators

· ENV: Environmental indicators

· SOC: Social indicators

The Eco-PACT Model has three primary indicators: Economic indicators ECO, Environmental indicators ENV, and Social indicators SOC.

The three primary indicators ECO, ENV and SOC have negligible error u_i.
Three secondary indicators are EC, GGE and ER, which correspond to the weight α_i.
Five tertiary indicators are MD, ED, FD, PED, CDD, which corresponding coefficients are w_{ij}

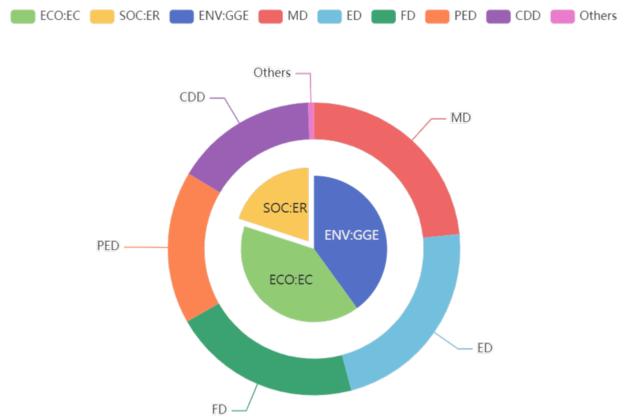

Figure 10: Eco-PACT model

5.3 Expressions of Eco-PACT

According to the LIMG model in Section 4 [Equation (5)], GGE can be constructed as a linear equation of the indicators. Therefore, we can construct the following equations:
$ECO = \alpha_1 \cdot EC + u_1$
$ENV = \alpha_2 \cdot GGE + u_2$
$SOC = \alpha_3 \cdot ER + u_3$
$EC = w_{11} \cdot MD + w_{12} \cdot ED + w_{13} \cdot FD + w_{14} \cdot PED + w_{15} \cdot CDD + w_{16}$
$ER = w_{31} \cdot MD + w_{32} \cdot ED + w_{33} \cdot FD + w_{34} \cdot PED + w_{35} \cdot CDD + w_{36}$
$GGE = w_{21} \cdot MD + w_{22} \cdot ED + w_{23} \cdot FD + w_{24} \cdot PED + w_{25} \cdot CDD + w_{26}$

Core expressions

$$\boldsymbol{Eco - PACT_{value} = f\left(\alpha_1 \cdot EC - \alpha_2 \cdot GGE + \alpha_3 \cdot ER\right) = f\left(ECO - ENV + SOC\right)} \tag{7}$$

Attention: Global data is used in this section, which is different from the country data in Section 4.

A reasonable weight allocation scheme is given based on a comprehensive consideration of the importance and actual impact of each indicator.

In the evaluation, more economic and environmental factors are considered rather than social factors, so higher weights are given to the former.

$$\alpha_1 = \alpha_2 = 0.4, \alpha_3 = 0.2$$

$$\therefore Eco - PACT_{value} = 0.4 \cdot EC - 0.4 \cdot GGE + 0.2 \cdot ER$$

Where EC and ER are normalized to between 0 and 1, GGE is normalized to $0 \sim 1$ and then reduced by one to normalize it to $-1 \sim 0$, making the Eco-PACT evaluation value between $0 \sim 1$.**The higher the score, the better the policy evaluation.**

Combining the previous global impact analysis in Section 4 with multiple logistic regression, we obtain w_{ij}.

The coefficient matrix is obtained as follows:

$$\mathbf{W_{ij}} = \begin{pmatrix} -0.075 & 0.049 & 0.17 & -0.027 & -0.0067 & 0.83 \\ 0.024 & 0.63 & 0.24 & 0.21 & 0.23 & 0.18 \\ 0.47 & 0.089 & 0.31 & -0.082 & -0.091 & 0.62 \end{pmatrix}$$

5.4 Evaluation of GGDP policy

We used the data from 2009 to 2019 for the evaluation. Due to the financial crisis in 2008 and the epidemic in 2020, some of the GDP data for 2008 and 2020 are negative, which is not conducive to model analysis.

It is assumed that **the value of MD, ED, FD, PED, and CDD will be reduced by 10**% after adopting the GGDP policy.

The Eco-PACT evaluation score before and after the adoption of GGDP is calculated and listed below[Table 3].

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
GDP policy	0.391	0.663	0.597	0.535	0.492	0.459	0.410	0.368	0.366	0.313	0.265
GGDP policy	0.566	0.792	0.705	0.626	0.563	0.509	0.443	0.381	0.357	0.285	0.238

Table 3: Evaluation Score for Different Policies Based on Eco-PACT Model

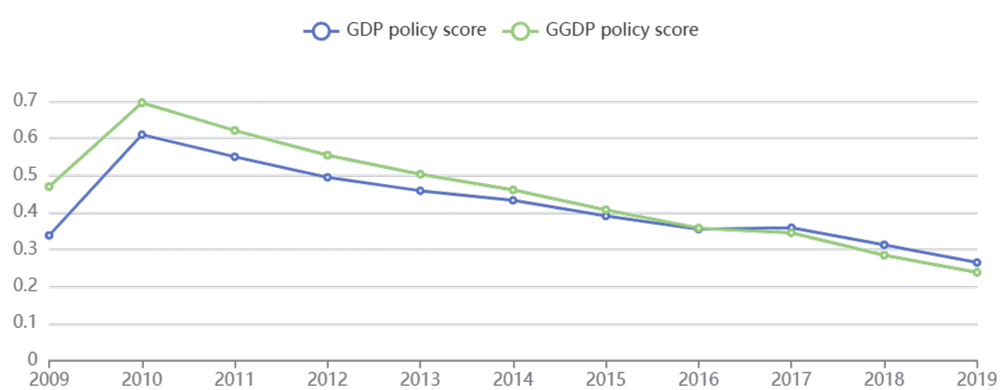

Figure 11: Evaluation Score for Different Policies Based on Eco-PACT Model

Based on the evaluation results, we can conclude that the GGDP score is higher than the GDP in most of the measured years. For the three years when the GGDP score is lower, the difference between the two policies remains narrow. By and large, GGDP can be adapted to replace GDP policy globally, gaining environmental benefits more than economic and other costs.

6 Country specific Analysis of India for GGDP Adoption

6.1 Environmental Condition of India

With a large population and a large land area, India is a representative country in world affairs. More importantly, India is seeking economic development while the country's ecosystem is being polluted. India is also proposing many environmental protection policies, which is exactly what GGDP is employed for.

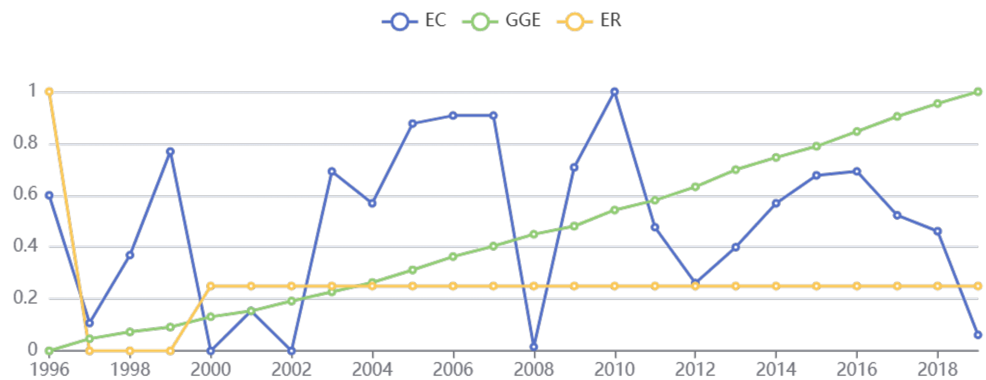

Figure 12: Global GDP growth, greenhouse gas emissions and employment of India

The data shows the changes in GDP growth rate, greenhouse gas emissions, and employment rate in India over a period of 25 years[Figure 12].

From the graph, we can see that the GDP growth rate has been increasing over the years, with a dip around the year 2012. The greenhouse gas emissions have also been increasing, although there seems to be a slight decline in recent years. The employment rate has been relatively stable, with a slight increase in the early years and a slight decline in the later years.

It is worth noting that while the increase in GDP growth may be seen as a positive sign, the concurrent increase in greenhouse gas emissions is a cause for concern, especially considering the commitment of India to reducing its carbon footprint. The stability of employment rate may be seen as a positive aspect, but it also raises questions about the quality of the employment and whether the growth is inclusive.

Overall, the data suggest a need for a more sustainable and inclusive approach to economic growth in India.

6.2 Alteration

According to the conclusion of indicator contributions in Section 4, the specific changes regarding the characteristics of India after adopting the GGDP policy are:

MD reduced by 20%
PED reduced by 10%
CDD reduced by 5%

Which could be achieved by
(a)reducing mining, by shifting away from coal towards renewable energy sources such as solar, wind, and hydropower.
(b)reduce air pollution, by promoting the use of electric vehicles, improving public transportation and managing industrial emissions.

6.3 Evaluating GGDP Policy of India with Eco-PACT Model

The Eco-PACT model proposed in Section 5 is employed. The primary difference is that model in this section would target at India, not globally.

The evaluation procedures are the same as the previous analysis. That is:
$Eco - PACT_{value} = 0.4 \cdot EC - 0.4 \cdot GGE + 0.2 \cdot ER$

Where EC, ER are normalized to between 0 and 1, GGE is normalized to $0 \sim 1$ and then reduced by one to normalize it to $-1 \sim 0$, making the Eco-PACT evaluation value between $0 \sim 1$.The higher the score, the better the policy evaluation.

Combining the model with multiple logistic regression, we obtain w_{ij}.

The coefficient matrix is obtained as follows:

$$\mathbf{W_{ij}} = \begin{pmatrix} -0.0086 & 0.053 & 0.15 & -0.031 & -0.0083 & 0.76 \\ 0.018 & 0.58 & 0.18 & 0.23 & 0.18 & 0.21 \\ 0.51 & 0.097 & 0.29 & -0.075 & -0.082 & 0.51 \end{pmatrix}$$

The Eco-PACT evaluation score before and after the adoption of GGDP for India is calculated and listed below[Table 4].

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
GDP policy	0.541	0.632	0.408	0.302	0.330	0.379	0.405	0.388	0.298	0.253	0.075
GGDP policy	0.594	0.669	0.463	0.361	0.378	0.417	0.435	0.413	0.324	0.278	0.112

Table 4: Evaluation Score for India Based on Eco-PACT Model

Predicting the Eco-PACT value for the next decade[Table 5].

Unlike the global evaluation, the GGDP policy predicting score for India is lower than the existing GDP policy. Probably because there is still a lot of potential for improvement in the overall economic and industry in India. A switch to the GGDP policy would probably cause more damage to the Indian economy and living conditions.

Year	2023	2024	2025	2026	2027
GDP policy	0.308	0.300	0.293	0.286	0.279
GGDP policy	0.311	0.295	0.279	0.263	0.247

Table 5: Evaluation Score for India Based on Eco-PACT Model

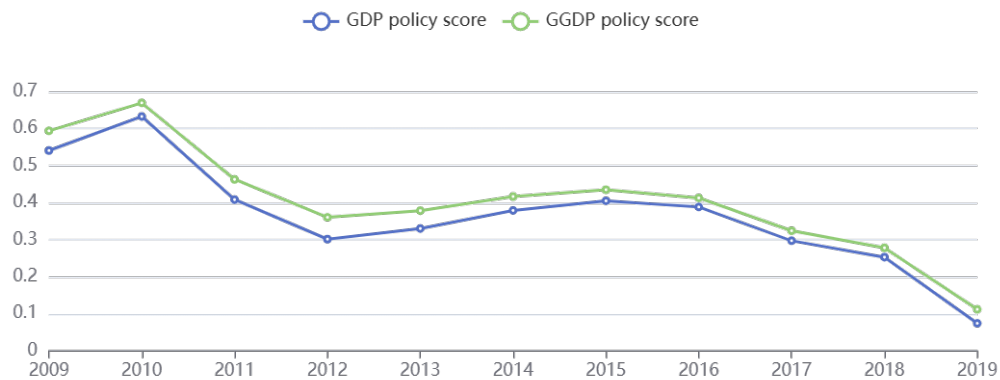

Figure 13: Evaluation Score for India Based on Eco-PACT Model

Based on this observation and the will to protect the environment, we propose the United Nations Subsidy Policy(UNSP) and apply it to the model. The UNSP states that, UN will subsidize the cost of environmental protection according to the contribution to climate mitigation. Specifically speaking, the amount of the subsidy will be calculated roughly based on the amount of GGE change, and will be approximately 10% of the economic benefits of climate mitigation.

The model for GGDP policy is modified as:

$$Eco - PACT_{value} = 0.4 \cdot EC - 0.4 \cdot GGE + 0.2 \cdot ER + 0.1 \cdot GGE$$

$$= 0.4 \cdot EC - 0.3 \cdot GGE + 0.2 \cdot ER$$

Then the prediction results change to

Year	2023	2024	2025	2026	2027
GDP policy	0.308	0.300	0.293	0.286	0.279
GGDP policy	0.343	0.327	0.314	0.305	0.277

Table 6: Evaluation Score for India After UN Subsidy Policy

After the modification, the GGDP policy becomes the preferred choice.

7 Discussion

Model Evaluation and Optimization

First of all, the data used in this article are from World Development Indicators, but there are many sources to obtain the data. Because of the different statistical methods, the data from different sources may be different. This variability will reduce the generalizability of our model to a certain extent. To ensure the generalizability of our model, we choose the most widely used World Development Indicators as the source of data.

In the second question, using RNN models for parameter evaluation may lead to overfitting results because of the limitation of data volume. Therefore, we try to adopt multiple models to evaluate the parameters. In addition to the RNN model, we also analyze the data with VAR model and multiple linear regression model to compare the similarity and difference of the output results of different models, and synthesize the results of different models to obtain conclusions to improve the accuracy of the model.

In the third and fourth questions, because it is difficult to quantify the impact of policy changes on the national economy and environment with the existing models, we construct a new evaluation model Eco-PACT model to score the GDP and GGDP policies and evaluate the advantages and disadvantages of the two policies. The reason for the error of the model may be the limited time duration of the time series data, which may lead to the not very accurate results of the time series prediction. We try to include important indicators in the Eco-PACT model to provide a more concise and comprehensive measure of the impact of the policies.

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Report to the Leaders of India:

Supporting a Switch to GGDP as the Primary Measure of National Economic Health

Team: #2309882

Introduction

India is on a trajectory to become the world's third-largest economy by 2030, but this growth must not come at the expense of the environment. To achieve a balance between economic growth and environmental protection, India needs to adopt a comprehensive and holistic approach that considers the long-term sustainability of economic growth. GDP has long been the primary measure of the economic health of a country, but it has limitations. This report advocates for a switch to Gross GGDP (GGDP) as the primary measure of national economic health, which takes into account the environmental costs of economic growth.

The Limitations of GDP

GDP only measures the value of goods and services produced within the borders, without considering the environmental cost. India has massive environmental challenges, including pollution, deforestation, and climate change, affecting significantly on the health and economy of the country and people.

The Benefits of GGDP

GGDP incorporates the environmental costs of economic growth, providing a more accurate measure of a country's economic health. It takes into account the value of resource depletion and environmental loss, especially energy depletion, mineral depletion, forest depletion, particulate emission damage, and carbon dioxide damage.

The Benefits for India

The economic growth of India is largely driven by industries such as mining, and manufacturing, and which have had adverse effects on the environment. India's energy sector largely relies on coal, a source of greenhouse gas emissions. By switching to GGDP, India can better balance economic growth with environmental protection, creating a more sustainable future for the country and its citizens. It will also promote a more holistic approach to economic development that takes into account the long-term value of natural resources and ecosystem services.

Conclusion

A switch to GGDP is necessary to accurately measure a country's economic health and balance economic growth with environmental protection. India can lead the way in this area, creating a more sustainable future for the country and the world.