Analysis of Green GDP Based on Multiple Linear Regression Model

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Abstract. GDP is an important indicator to measure a country's economic situation. However, with the development of our society, GDP can no longer represent the real situation of a country' economy, since it does not take into account the sustainability of a country's economic development. Thus, green GDP, also known as GGDP came into being. GGDP not only measures a country's economic achievements in the past, but also measures its ability of sustainable development in the future. Based on the linear regression model of GGDP, this paper analyzes the factors that may affect a country's GGDP, and further discusses the influences of GGDP on a country's sustainable development.

Keywords: Green GDP, Multiple Linear Regression Model, Climate Change.

1. Introduction

Green GDP is a general indicator of economic regulation for both environmental protection and resource reservation [1]. The measurement of GGDP is a very sophisticated process. Unfortunately, in the research and practice of green GDP, there are differences in the expression of green GDP, lacking a unified and standardized definition at present [2]. GGDP is not only related to a country's GDP but also to a country's greenhouse gas emissions, vegetation coverage, biodiversity, and so on. Several countries and organizations have already adopted GGDP as a measure of society progress. The United States is the first country in the world to study green GDP. As early as the Ford Administration (1974-1977), the Bureau of Economic Analysis of the U.S. Department of Commerce (hereinafter referred to as BEA) calculated the cost of environmental pollution control according to the requirements of the then Minister of Commerce [3]. And in China, the green GDP accounting system has included the value of ecosystem services, but the accuracy and reasonability of ecosystem services accounting at present cannot meet the requirements of green GDP accounting. Although there are many proposed ways to calculate GGDP that have already been developed, overall, GGDP accounting is in its initial stage up to present time. Despite some challenges and limitations, the concept of GGDP continues to gain traction as a way to promote sustainable development and prioritize environmentally-friendly policies and practices.

2. A Multiple Linear Regression Model of GGDP

2.1. Several factors related to GGDP

According to the definition of GGDP, it is clear that many factors of a country may contribute to the country's GGDP. However, in order to study the influence of GGDP on climate, this paper only considers the climate-related factors that may affect GGDP.

Different experts have different views on GGDP accounting method and the factors affecting it. Therefore, this paper first collected relevant information and explored the factors that may be related to GGDP. They are carbon dioxide emissions, vegetation area, number of species, sulfur dioxide emission, and vegetation types. In order to judge whether there is a linear relationship between them and GGDP, this research makes scatter diagrams of them and GGDP respectively and try to analyze them. The relationship between carbon dioxide emissions, vegetation area, number of species, Sulfur dioxide emission, and vegetation types between GGDP is shown below.

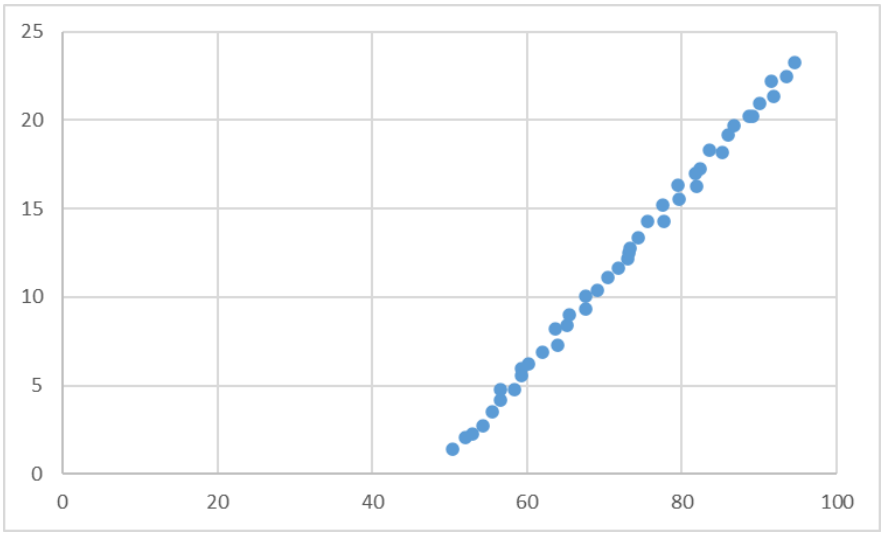

Figure 1. Scatter Diagram of Relationship between Carbon Dioxide Emissions and GGDP

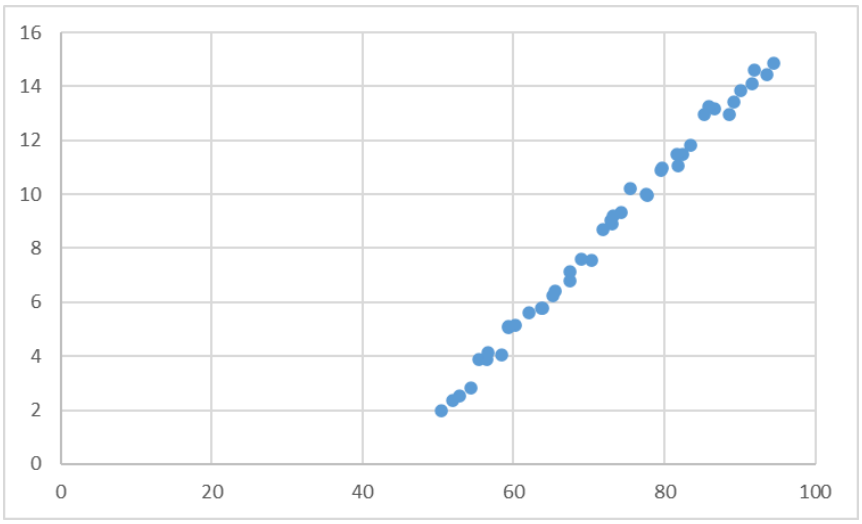

Figure 2. Scatter Diagram of Relationship between Vegetation Area and GGDP

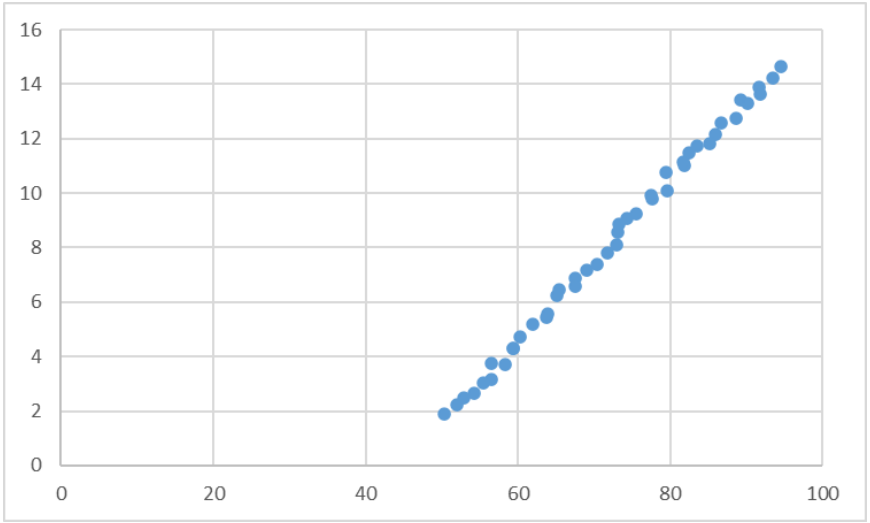

Figure 3. Scatter Diagram of Relationship between Number of Species and GGDP

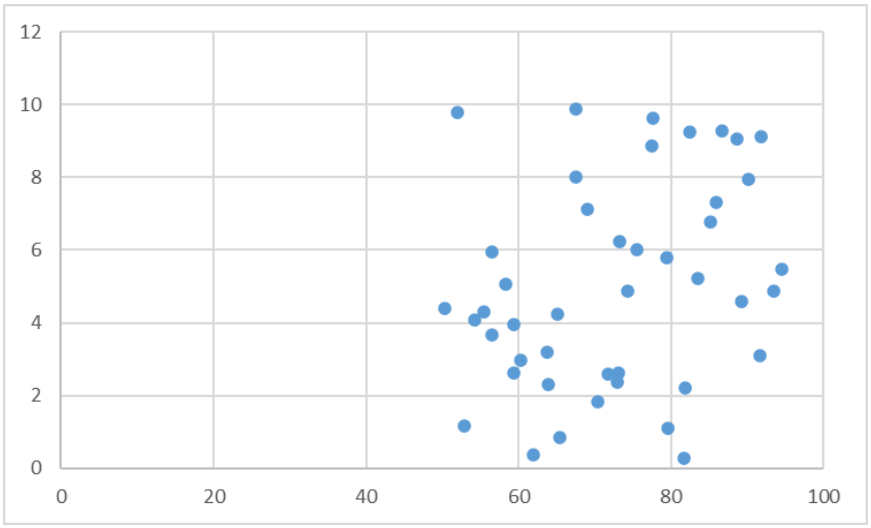

Figure 4. Scatter Diagram of Relationship between Sulfur Dioxide and GGDP

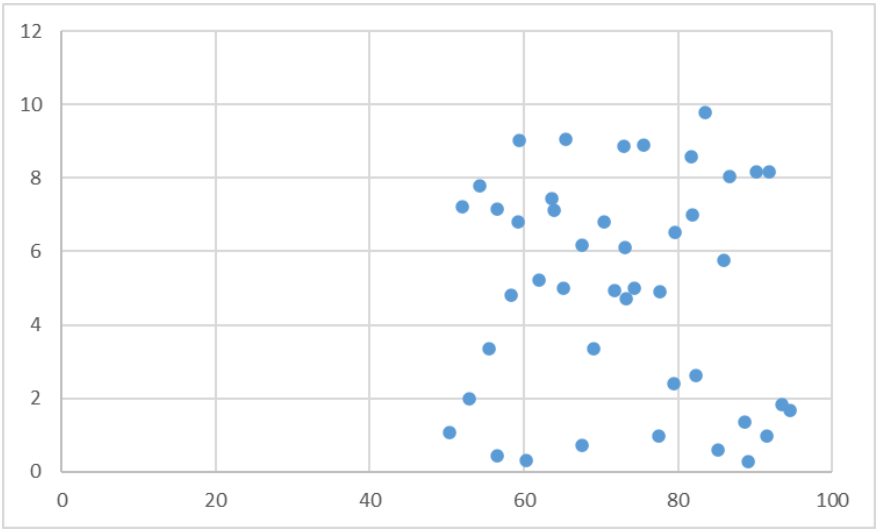

Figure 5. Scatter Diagram of Relationship between Increased Vegetation Types and GGDP

There are most probably linear relationships in Figure 1, Figure 2 and Figure 3. However, in Figure 4 and Figure 5, a linear relationship appears impossible. Hence, the research preliminarily believes that there is a linear relationship between carbon dioxide emissions, vegetation area, number of species, and GGDP.

2.2. Setting up the linear regression model

In order to verify the relationship between the above five variables and GGDP, the following model is established.

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 \quad (1)$$

The meaning of each letter in the above formula is shown in the table below.

Table 1. Letter Representation

Letter	Meaning
y	GGDP
x_1	carbon dioxide emissions reduction
x_2	vegetation area increases
x_3	number of species increase
x_4	sulfur dioxide emission reduction
x_5	vegetation types increase
a_0, a_1, a_2, a_3, a_4, a_5	parameter

The research used the data of several countries' GGDP and relative factors to make a linear regression by using STATA to the equation (1) and got the following results.

```
. reg GGDP CO2emission vegetationarea numberofspecies Sulfurdioxideemission vegetationtypes
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Source	SS	df	MS	Number of obs	=	44
				F(5, 38)	=	3656.73
Model	7156.69686	5	1431.33937	Prob > F	=	0.0000
Residual	14.8741861	38	.391425951	R-squared	=	0.9979
				Adj R-squared	=	0.9977
Total	7171.57105	43	166.780722	Root MSE	=	.62564

GGDP	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
CO2emission	.8364889	.338155	2.47	0.018	.1519299	1.521048
vegetationarea	.6759769	.326214	2.07	0.045	.0155911	1.336363
numberofspecies	1.280257	.5246503	2.44	0.019	.2181581	2.342356
Sulfurdioxideemission	-.000715	.0358659	-0.02	0.984	-.0733217	.0718917
vegetationtypes	-.0045354	.0337538	-0.13	0.894	-.0728665	.0637956
_cons	45.91088	.7181945	63.93	0.000	44.45698	47.36479

Figure 6. Stata Regression Result

The results of STATA regression verify our previous conjecture. As can be seen from the above figure, the T value of carbon dioxide emission, vegetation area, number of species, sulfur dioxide emission and vegetation types are 2.47, 2.07, 2.44, -0,02 and -0.13. Hence, it can be concluded that there are linear relationships between carbon dioxide emission, vegetation area, number of species, and GGDP. And there are not linear relationships between GGDP and sulfur dioxide as well as vegetation types.

To sum up, this paper gets the linear model of GGDP, as shown below:

$$y = 45.882 + 0.834x_1 + 0.667x_2 + 1.295x_3 \quad (2)$$

The above equation shows that for every unit of carbon dioxide emission reduction, every unit of vegetation area increase, and for every unit of species increase, GGDP increases by 0.824, 0.667 and 1.295 units respectively.

2.3. Evaluation of Multiple Linear Regression Model of GGDP

2.3.1. Strengths of the Model

The Multiple Linear Regression Model of GGDP has several advantages, including broad-range application, simplicity of its form as well as with strong theoretical support

First of all, the Multiple Linear Regression Model of GGDP is robust while the parameters change, namely, a slight change in parameter will not cause a significant change in the results. Hence, it can be easily modified to accommodate various situations and countries.

Secondly, the Multiple Linear Regression Model of GGDP only uses a multiple linear regression method to measure GGDP and thus creating a very simple equation which can avoid complicated calculations.

Thirdly, the Multiple Linear Regression Model of GGDP is supported by a large number of theories and methods, which of whom are reasonable and proper.

2.3.2. Weaknesses of the Model

There are also some disadvantages for the Multiple Linear Regression Model of GGDP, they are the regardless of non-linear relationships of some factors and GGDP, the model requires some data that are difficult to obtain as well as that the model only pays attention to the factors which are related to climate.

The Multiple Linear Regression Model of GGDP only considers the linear relations between certain factors and GGDP. By acting the linear regression, this paper figured out the factors which contribute to a country's GGDP. However, the model does not take those non-linear relationships into account.

Some of data required by the Multiple Linear Regression Model of GGDP can be found with difficulties. In the practice, some data need to be inferred from the overall situation of this country. This will lead to some errors in the model.

Last but not least, the Multiple Linear Regression Model of GGDP only considers the factors which are related to climate. Since this is paper is written to discuss the impact of GGDP on climate, those factors which are not related to climate were not taken into measure when the model was established.

3. Apply the Model to Analyze the Situation of Germany

3.1. Introduction to the Current Situation of Germany

Germany is located in central Europe, bordering Denmark in the north, the Netherlands, Belgium, Luxembourg, and France in the west, Switzerland and Austria in the south, and the Czech Republic and Poland in the east. The country consists of 16 federal states, with a territory area of 357,582 square kilometers and a temperate climate. With a population of about 83.19 million, Germany is the most populous country in the European Union.

Germany's environmental economic accounting framework includes three parts: environmental pressure, environmental state and environmental response, which are interrelated and influenced each other [4]. Germany is relatively poor in natural resources. Except for the rich reserves of hard coal, lignite and salt, it relies heavily on imports in raw material and energy, and 2/3 of the primary energy needs to be imported. Germany always pays much attention to environment protection. For instance, in the process of agricultural development, Germany has formulated a set of perfect legal system to regulate agricultural production and imposes corresponding penalties for acts that damage the environment in agricultural production [5].

Germany is a highly developed industrial country. Germany is the only European country that has made the transition to Industry 4.0, and the rate of return on capital used has been significantly improved, from 12% in 2000 to over 30% in 2014. In the past decade, new technologies such as artificial intelligence, blockchain and 5G have opened up new opportunities for Industry 4.0, and more and more industrial enterprises around the world are also transforming their digital production, services and even business models [6].

The economic aggregate of Germany ranks first in Europe and fourth in the world. From 2008 to 2016, the trend of GDP and GGDP in Germany is shown in Figure 7.

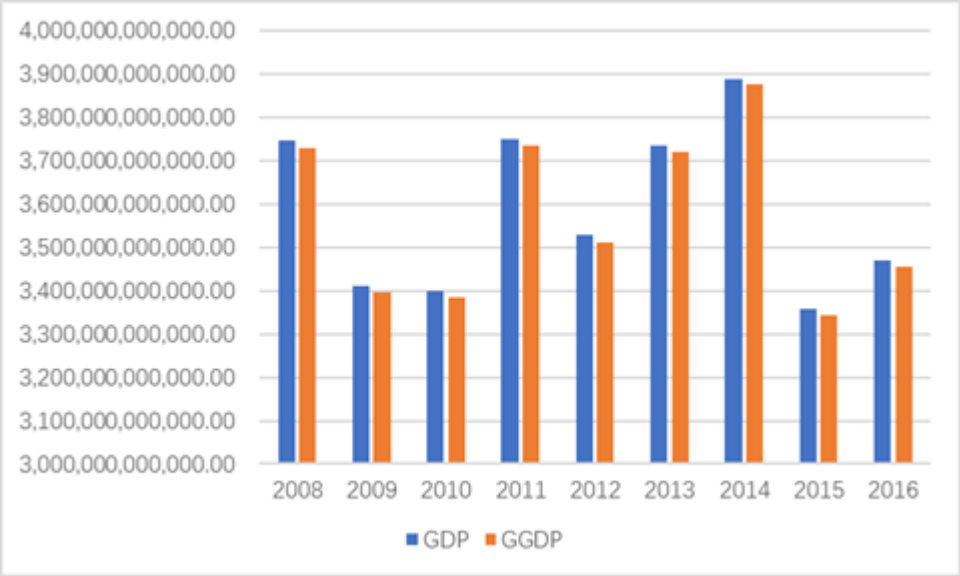

Figure 7. GDP and GGDP of Germany from 2008-2016 Unit: Dollar

From a global point of view, German GGDP's deviations from the GDP (in %) are small. Top five economies deviations from GDP are shown in Table 2. Among the top five economies in the world, GGDP's deviations from the GDP (in %) of the United States, China, Japan, Germany, and Britain in 2016 are 0.1, 0.1, 0.1, and 0.1. The chart below shows the difference between the GGDP and GDP of the top five economies in the world.

Table 2. GGDP's Deviations from the GDP (in %) of the World's Top Five Economies in 2016

Rank	Country	GGDP's deviations from the GDP(in %)
1	United States	-0.51
2	China	-2.16
3	Japan	-0.43
4	Germany	-0.41
5	UK	-0.61

3.2. Impact of Replacing GDP by GGDP of Germany

3.2.1. Overview of the Impact

There is no doubt that if GGDP is used to replace GDP, it will have an impact on Germany in many aspects. This influence is not only in the process of economic accounting, but also has a far-reaching impact on Germany's development concept and model. To improve GGDP, Germany will reduce carbon dioxide emissions and take measures to protect forests and the ecological environment. Of course, in this process, the issue of climate change will be placed in an important position. To a certain extent, the process of improving GGDP is the success of mitigating climate change. Next, this research will specifically introduce the impact brought to Germany by using GGDP instead of GDP.

3.2.2. Reduce Carbon Dioxide Emissions

Tracing back to the source, greenhouse gas emissions, especially carbon dioxide emissions, are one of the most important causes of global warming [7]. Hence, low-carbon development is an extension and concretization of human sustainable development, which requires economic growth, social equity and environmental protection [8].

Since 1990, Germany's carbon dioxide emissions in kilograms have shown a downward trend. This reflects the progress of science and technology and the improvement of environmental awareness in Germany. Since 1990, the trend chart of Germany's carbon dioxide emissions is as follows:

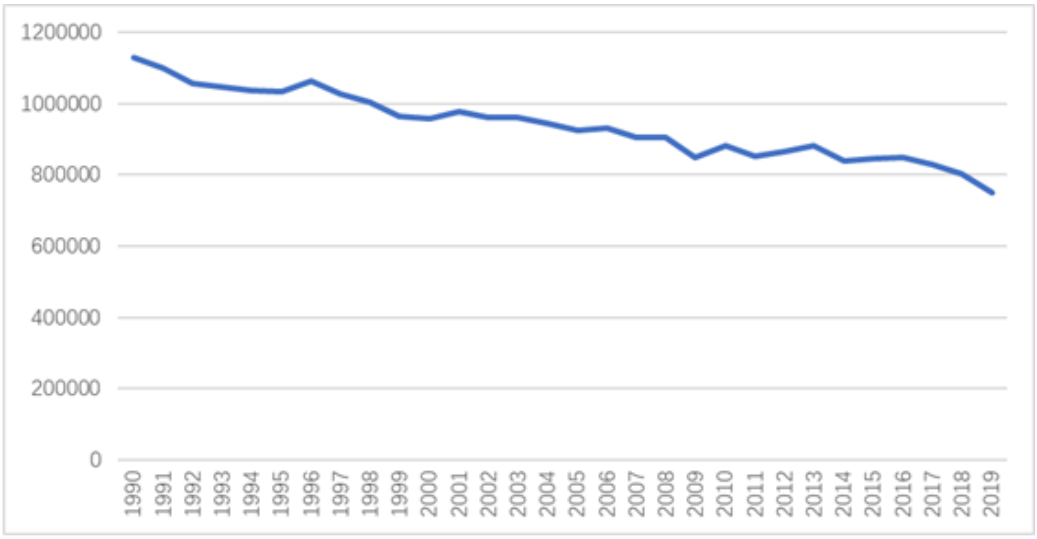

Figure 8. Germany Carbon Dioxide Emissions Since 1990 Unit: KG

GGDP takes carbon dioxide emissions into account as an important factor, which can further promote Germany to reduce carbon dioxide emissions. If Germany takes GGDP as an indicator to measure economic development, then it will weigh between further increasing GDP and improving environmental protection, which will undoubtedly promote Germany to find ways to reduce carbon dioxide emissions.

3.2.3. Protection and Restoration of Vegetation

Forest vegetation has an impact on climate in two ways: the "carbon" pool and the underlying surface.

Forest is the largest carbon pool on land, and the relative changes of photosynthesis and respiration of forest ecosystem determine whether forest ecosystem is a sink or a source, which has different effects on climate. Human disturbance has an obvious influence on the process of the forest carbon budget. Climate change has a serious impact on forests and forest management, but forest management and the utilization of forest products can be important tools to slow down climate change [9].

As early as 200 years ago, Germany introduced the concept of sustainable forest management and implemented the development strategy of multi-benefit sustainable utilization of forests. Since then, sustainable forest management has been developed, and the certification of sustainable forest management has also emerged [10]. Since 1990, the proportion of forest area in Germany's land area in percentage has remained at around 32.00%. This proportion is at the world average level. Although this indicator is influenced by geographical location, climate, and other factors, the situation in different countries is not exactly the same, however, it is still meaningful to compare the proportion of forest area in Germany with the global situation.

In recent years, the forest area in Germany has declined. If GGDP is used as an indicator to measure economic development instead of GDP, to improve GGDP, Germany will make a trade-off between developing the economy by destroying forests and properly reducing the economic growth rate but restoring vegetation, which is very beneficial to restoring forests and improving climate.

3.3. Result

Based on the GGDP Linear Regression Moel, this paper believes that Germany has enough ability to support future generations' wellbeing.

First of all, Germany's economic aggregate is large. Though Germany's GDP output value has fluctuated in recent years, the overall GDP and GGDP output level is high. This has accumulated rich material wealth for future generations.

Secondly, Germany's greenhouse gas emissions are decreasing year by year. Since 1990, Germany's carbon dioxide emissions have been decreasing. Although this declining trend is difficult

to last forever, however, if carbon dioxide emissions can be kept at a low level, its impact on the environment will be limited and it will not put pressure on the economic development in the future.

Thirdly, Germany's resource reserves and forest area are at a reasonable level. The proportion of forest area in Germany exceeds the global average, and it is on the rise. Although the reserves of mineral resources in Germany are small, Germany has effectively alleviated this problem through international trade and other means. Therefore, from the perspective of resources, this paper believe that Germany can support the development of latecomers.

In a nutshell, through the analysis of the main factors that constitute GGDP, this paper feels that Germany has good economic development, a healthy ecological environment, and sufficient resource reserves, which have laid a sound foundation for the development of future generations.

4. Conclusion

On the whole, the Linear Regression Model of GGDP well measures the influence of climate-related factors on GGDP, and quantitatively measures the influence of carbon dioxide emission, vegetation area and number of species on a country's GGDP. By applying the model to the situation of Germany, this paper think that the sustainable development of Germany is good, its economic development has little impact on the climate, and it has a good ability to support future generations.

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