Empirical Study on Green GDP Accounting of Various Provinces in China - PVAR Analysis Based on Provincial Panel Data

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Abstract. With China's rapid economic development, the demand for natural resources is increasing, and resource and environmental issues have become serious constraints to sustainable economic development, so it is especially important to adopt green GDP instead of traditional GDP to measure a country's sustainable development. Based on the resource and environment perspective, this paper accounts for the green GDP of each province in mainland China from 1997 to 2020 by constructing a green GDP accounting system, and divides provinces according to energy use efficiency, and establishes a panel vector autoregressive model (PVAR) between green GDP and environmental and economic indicators in energy-efficient, medium-efficient and inefficient regions based on the panel data of each province for empirical research. It was found that the effects of each variable on green GDP differed among the divided regions. In the energy-inefficient and energy-medium zones, both the total consumption of CO2 clean mechanism trade and the total consumption of solid waste recycling have positive effects on green GDP development, while in the energy-efficient zone, only the total consumption of solid waste recycling has a positive effect on green GDP, while the total consumption of energy has a negative effect. To achieve sustainable green GDP development, we need to take comprehensive measures, including improving CO2 clean mechanism trading, enhancing solid waste recycling and sustainable disposal, reducing reliance on electricity and coal, finding sustainable alternatives to crude oil, and integrating natural gas resources with renewable energy. Achieving a long-term driving effect on green GDP.

Keywords: Sustainable development; Green GDP; Energy consumption; PVAR model

1. Background

Since the reform and opening up, China's economy has grown rapidly, causing environmental damage. To address this issue, the 20th CPC National Congress emphasized "modernizing human life in harmony with nature" as a core element of "Chinese-style modernization," focusing on green development. The 14th Five-Year Plan prioritizes a green economy, green development policies, tax policies for conservation, and promoting green finance. It aims to limit high-energy and high-emission projects and replace traditional GDP with green GDP.

The concept of green GDP arose in the early 1990s. Inspired by various international conferences in the 1990s, the concept of sustainable social and economic development was introduced and received global attention[1]. This culminated in the first international framework for environmental (green) accounting by the United Nations System of Environmental-Economic Accounting (SEEA), and in 2012, the first international statistical standard for environmental-economic accounting was formed: the SEEA-Central Framework[2].

Through the organization of related literature, it is found that there are narrow and broad definitions of green GDP[3]. Jinkai Shi et al. use a vector autoregressive model (VAR) to study the relationship between total energy consumption and green GDP growth[4].

At this stage of research, the measurement methods and accounting objects of green GDP are diversified, and the analysis of inter-regional differences and spatio-temporal differences has yet to be strengthened. In order to explore the dynamic relationship between energy consumption and green GDP in each province, this paper constructs the PVAR model[5], and comprehensively analyzes the dynamic influence mechanism of the two through generalized moment estimation, impulse response and variance decomposition.

2. Data sources and related variables

2.1. Data sources

The empirical study in this paper is conducted on provincial green GDP in mainland China, and the time period of the study is 1997-2020.Considering the serious lack of data in Tibet, Xinjiang, Qinghai, etc., these regions are not taken into account in the analysis, and the data of 28 provinces and municipalities directly under the central government are finally selected. The data used in the study come from the National Bureau of Statistics, provincial statistical yearbooks, China Energy Statistical Yearbook and World Energy Statistical Yearbook. When dealing with some missing data, Bayesian estimation and great likelihood methods were used for estimation. To ensure the robustness, completeness and compatibility of the results across provinces, all data were thoroughly checked.

2.2. Related variables

(1) Green GDP (GGDP): Green GDP is a measure of economic growth and environmental sustainability, which aims to separate economic growth from negative environmental impacts to reflect the environmental benefits of economic activities.

(2) Total CO2 Clean Mechanism Trading Consumption (co2): Total CO2 Clean Mechanism Trading Consumption is the total amount of consumption used by a country or region to purchase or sell carbon emission allowances in the CO2 (carbon dioxide) Clean Mechanism Trading market.

(3) Total Consumption of Solid Waste Recycling (SOLID): Total consumption of solid waste recycling is the total amount of money spent by a country or region in the field of solid waste recycling.

(4) Total Electricity and Coal Consumption (COAL): Total coal consumption refers to the sum of the amount of coal used by a country or region in the process of generating electricity.

(5) Total crude oil consumption (oil): Total crude oil consumption refers to the total amount of crude oil used and consumed by a country or region in a specific time period.

(6) Total natural gas consumption (gas): Total natural gas consumption is the total amount of natural gas used by a country or region over a specific period of time.

3. Model construction

3.1. Calculation of Green GDP

Green GDP is calculated by subtracting the cost of natural resource consumption and the cost of environmental consumption from traditional GDP indicators. The goal of the methodology is to create a single (measurable in monetary terms) indicator, similar to the concept of Green GDP, and effectively linked to traditional GDP data.

Green GDP = GDP - (CO_2 emissions in tons × average price of the Clean Development Mechanism for purchasing CO_2 emissions trading) - (waste in tons × 74 kilowatt-hours of electricity × price of 1 kilowatt-hour of electricity) - (gross national income/100 × total economic output from natural resource extraction as a percentage of gross national income);

or simplified as:

$$Green\ GDP = GDP - (KtCO2 \times PCDM) - (Twaste \times 74kWh \times Pelect) - (\frac{GNI}{100} \times \%\, NRD) \quad (1)$$

Green GDP refers to Green Gross National Product (RMB), GDP refers to Gross National Product (RMB), KtCO2 refers to CO_2 emissions (kilotons), PCDM is the average price of the Clean Development Mechanism (RMB/tonne); Twaste refers to the total production of commercial and industrial wastes, 74kWh refers to the consumption of 74 kilowatt-hours (kWh) of electricity, Pelect refers to the price needed to use 1 kWh of Pelect refers to the price required to use 1 kWh of electricity (using the average of commercial and industrial electricity prices by province); GNI refers to Gross National Income (due to the lack of data on provincial net incomes from foreign sources, provincial GDP is used instead of GNI), and NRD refers to the total amount of economic output obtained from the exploitation of natural resources, including the sum of consumption of forest consumption, energy consumption, and mineral consumption (due to the lack of data on forest consumption and mineral consumption in some provinces, the sum of consumption of forest consumption and energy consumption is used instead of NRD). Energy consumption is used instead of NRD). Total energy consumption includes coal consumption (using the average price of industrial and commercial electricity in each province), crude oil consumption (using international crude oil prices converted using the Renminbi exchange rate), and natural gas consumption (using natural gas prices in each province).

3.2. Vector autoregressive model

Panel Vector Autoregressive (PVAR) models are used to study the dynamic relationship between two or more variables. In a PVAR model, all variables are treated as endogenous variables for empirical analysis, and the responses to shocks among variables are decomposed by orthogonalizing the error terms to reflect the dynamic interactions among different variables in the model. We constructed a PVAR model to study the dynamic relationship between green GDP, total consumption of CO_2 Clean Mechanism trading, total consumption of solid waste recycling, crude oil consumption, electricity and coal consumption, and natural gas consumption in each region, as shown below:

$$Z_{i,t} = \omega_0 + \eta_i + \theta_t + \sum_{j=1} w_j z_{i,t-j} + \varepsilon_{i,t} \quad (2)$$

where i = (1, 2, ..., i) denotes the number of provinces in each regional division; t denotes 1997-2020; r denotes the lagged order of the endogenous variables; $z_{i,t-j}$ is a vector of endogenous variables containing GGDP、*co2*、*solid*、*oil*、*coal*、*gas*; θ_t denotes a time effect and denotes a vector of time effects, reflecting trend characteristics; η_i denotes a vector of fixed effects, characterizing regional heterogeneity; $\varepsilon_{i,t}$ denotes a random perturbation term, and $\omega_0$refers to the intercept term.

The empirical analysis steps of PVAR mainly include panel unit root test, cointegration test, selection of lag order, estimation of PVAR model parameters, impulse response function analysis, and variance decomposition.

4. Empirical Tests and Analysis of Results

4.1. Parameter selection

Before the estimation of the PVAR model, the smoothness of the panel data can have an impact on the results. To avoid pseudo-regression, we first conducted the LLC (Levin-Lin-Chu) test and IPS (Im-Pesaran-Shin) test for the variables involved in the study.

The results shows that the variables ggdp_d1, co2_d1, solid_d1, coal_d1, oil_d1 and gas_d1 obtained after second-order differencing are smooth and can be used to construct the PVAR model.

Due to the differential treatment of the data, to avoid pseudo-regression, we used the Kao test to test for cointegration in the panel data. At the 1% significance level, we find that all three regions reject the original hypothesis that there is no cointegration between the variables. This indicates that there is a long-run equilibrium relationship between the six variables, namely green GDP, total consumption of CO2 clean mechanism trading, total consumption of solid waste recycling, crude oil consumption, electricity and coal consumption, and natural gas consumption, and thus regression estimation can be carried out on the panel data.

In order to avoid the bias of empirically estimated coefficients from time and fixed effects, we use the relevant information criterion to determine the optimal lag order of the PVAR model. By comparing the minimum values of the Akaike Information Criterion (AIC):

$$AIC = 2k - 2ln(L) \tag{3}$$

where k is the number of model parameters and L is the likelihood function.

Bayesian Information Criterion (BIC):

$$BIC = kln(n) - 2ln(L) \tag{4}$$

where k is the number of model parameters, n is the number of samples, and L is the likelihood function.

Hannan-Quinn Information Criterion (HQIC):

$$\mathrm{HQIC} = -2\ln(\mathrm{L}) + 2\mathrm{k}\ln(\mathrm{n}) \tag{5}$$

where k is the number of model parameters, n is the number of samples, and L is the likelihood function.

we can choose the optimal lag order to ensure the validity of the model estimation. Based on the results, we can draw the following conclusions: in the PVAR model for Energy Inefficient Zone and Energy Medium Efficiency Zone, the optimal lag order is 1. This means that a better model fit can be obtained by considering only the previous period's data as the lagged variable. For the Energy High Efficiency Zone, the BIC value is minimized at lag 1, but both the AIC and HQIC values show better results at lag 3. Therefore, we choose lag 3 as the optimal lag order for the Energy High Efficiency Zone model.

4.2. Model estimation

Based on the determined optimal lag order, we built a PVAR model including GGDP, co2, solid, oil, coal, and gas. However, direct model estimation may lead to biased results due to the presence of time and fixed effects in the PVAR model. Therefore, to eliminate these effects, we need to transform the relevant data.

First, the time effects of the variables are eliminated using the mean difference method, which is achieved by subtracting from each variable its average value at each point in time. The variables thus treated will have their time trends removed, making the model more focused on the changes in the relationship between the variables.

Second, we processed the data using the Helmert transform to remove fixed effects. The Helmert transform is achieved by gradually subtracting the mean of each variable. This will make the variables remove the effects of fixed effects, thus making the model estimation more reliable.

Finally, we estimate the model on the transformed data using GMM (Generalized Method of Moments)GMM is an estimation method based on the condition of moments that addresses endogeneity and mild qualitative modeling in the model. GMM the formula is as follows：

$$\log L(\theta) = \sum_{j=1}^{N} logP(x_j|\theta) = \sum_{j=1}^{N} log(\sum_{k=1}^{K} \alpha_k \, \varphi(x|\theta_k)) \tag{6}$$

In the Energy Inefficient Zone, we find that Green GDP is mainly influenced by electric coal and natural gas . This suggests that increased electric coal and natural gas in lag 1 will positively affect green GDP in the current period. The likely reason is that in Energy Inefficient Zones, the economic benefits of consuming electric coal and natural gas outweigh the environmental damage caused. In addition, the impact of green GDP on itself is -0.11 in lag 1 period, which is not significant but indicates that green GDP in Energy Inefficient Zone fails to achieve coordinated and sustainable development of itself. While the impacts of crude oil and CO2 on green GDP in lag 1 period are -0.61 and -0.40 respectively, although not reaching significant level, the negative impact indicates that the reduction of crude oil consumption and CO2 contribute to the development of green GDP.

Second, in the Energy Medium Efficiency Zone, we find that green GDP is mainly affected by crude oil consumption and itself. This suggests that increased crude oil and green GDP in lag 1 will positively affect green GDP in the current period, i.e., the positive effect of last year's green GDP has a continuing effect on this year's green GDP. In addition, solid waste and natural gas on green GDP in lag 1 period are -3.14 and -0.13, respectively, which do not reach a significant level, but the negative impacts indicate that reducing solid waste and natural gas can help to promote the development of green GDP.

Finally, in the Energy High Efficiency Zone, green GDP is mainly affected by itself. With a lag of 1 period, the coefficient of green GDP influence on itself is -0.19 and is significant at the 10% significance level. This indicates that the overall structure of green GDP in Energy High Efficiency Zone has not reached its own state of coordinated sustainable development. In addition, the impact of crude oil on green GDP is -0.41 in lag 1, which is not significant, but the negative impact indicates that reducing crude oil contributes to the development of green GDP.

4.3. Impulse Response Function Analysis

The impulse response function is a tool used to analyze the dynamic relationship between variables in time series data. It can be used to simulate the future response of a variable by introducing a shock of a random disturbance term in the model. This shock can be a shock of one standard deviation and is used to study how the variable is affected by itself and other variables. In this paper, by plotting impulse response plots using Stata 17.0 software, we can observe the dynamic relationships between variables more clearly and gain important insights about their interactions.

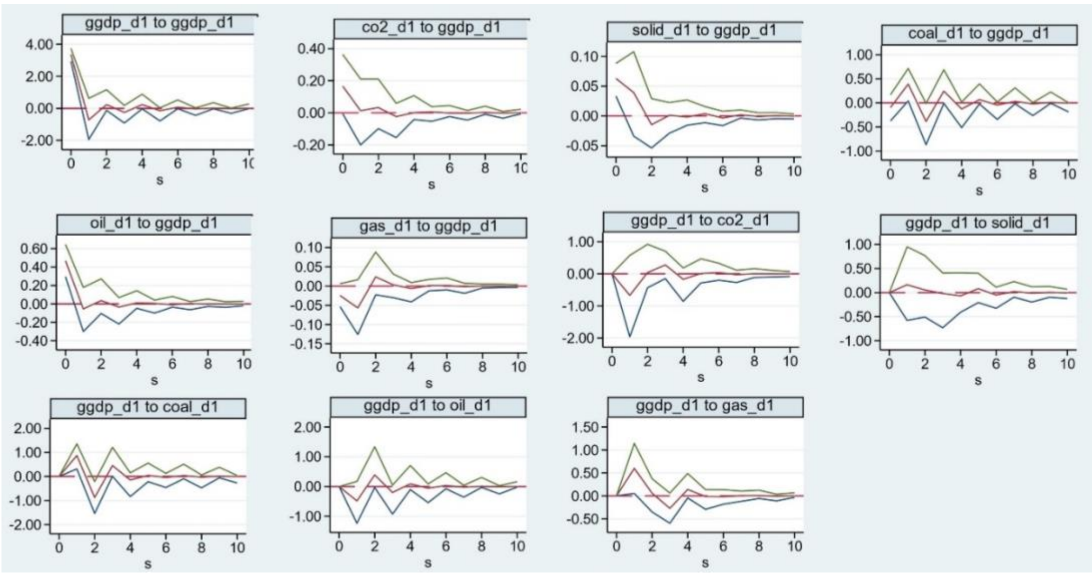

Fig 1. Impulse Response Plot for Energy Inefficient Zone

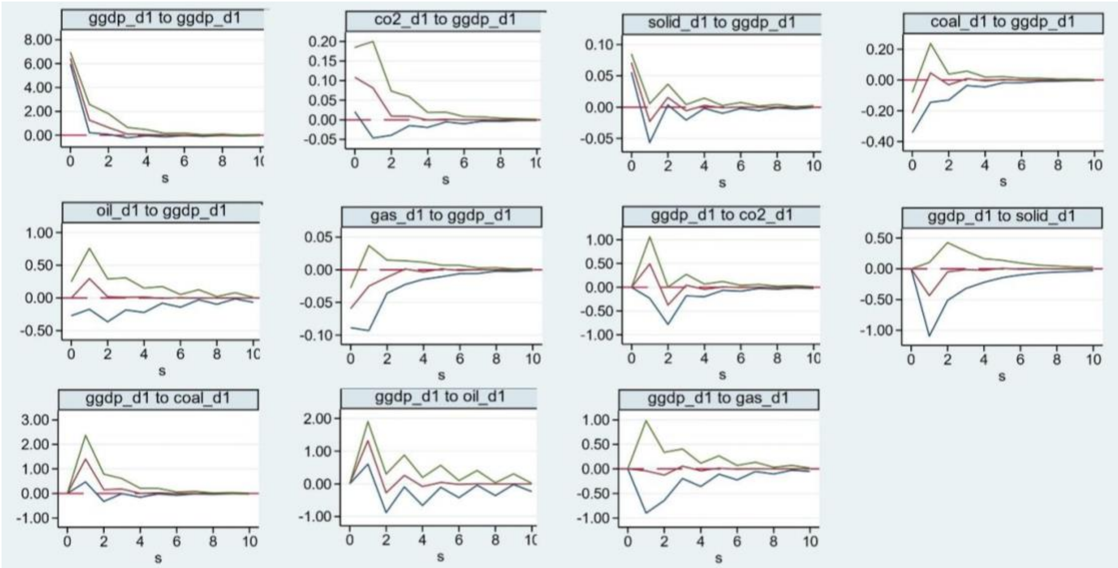

Fig 2. Impulse Response Plot of Energy Medium Efficiency Zone

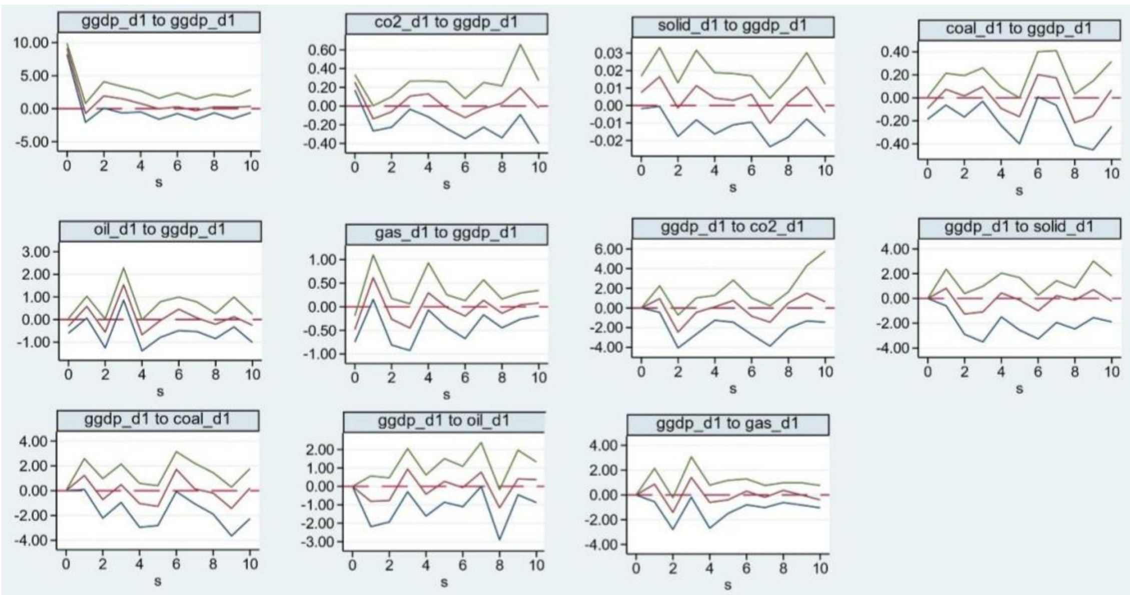

Fig 3. Impulse Response Plot for Energy High Efficiency Zone

The first column of graphs in each division of the region represents the response of green GDP after being subjected to different shock factors. The impact of each shock factor on green GDP is explained in detail below:

In the Energy Inefficient Zone and Medium Inefficient Zone: Carbon dioxide and solid waste have short-term positive impacts on green GDP, and their contribution to green GDP lacks stability. Coal has a short-term positive impact effect on green GDP, and there are instability and inhibition effect, so excessive increase in the use of coal can not promote the growth of green GDP because It causes more damage to the environment than its contribution to the economy. Crude oil has a positive impact on green GDP in the short term, but the long-term effect is not obvious, with both inhibitory and promotional effects, and there is still room for improvement in terms of stability, so it is necessary to look for sustainable energy alternatives to crude oil. The negative impact of natural gas on green GDP gradually converges to zero in the short term, suggesting that there may be potential benefits or equalizing effects in the long term. In the Energy High Efficiency Zone: The impact of CO2 on green GDP is unstable. Although there is a positive impact in the short term, the long-term effect is not obvious. Electricity, coal, and crude oil all have long-term effects on green GDP, both inhibiting and promoting, suggesting that there is instability in the development of green GDP from these three types of energy consumption, and the need to find energy substitutes.

In summary, the total consumption of CO2 Clean Mechanism Trading and the total consumption of Solid Waste Recycling have positive impacts on the three zones in the short term, while the impacts of energy consumption on the Green GDP of the Energy Inefficient Zone and the Medium Efficiency Zone are unstable and may bring about an inhibitory effect, and the impacts of the Energy High Efficiency Zone show alternating inhibitory and promotional effects. In order to achieve sustainable development, we need to encourage CO2 Clean Mechanism trading and solid waste recycling and actively develop new energy technologies to find sustainable energy alternatives.

4.4. Variance decomposition analysis

By visualizing the dynamic relationship between endogenous variables through the impulse response and combining it with the variance decomposition method, the degree of interactions among the six variables, namely, green GDP, total consumption of CO2 Clean Mechanism transactions, total consumption of solid waste recycling, crude oil consumption, electricity and coal consumption, and natural gas consumption, can be assessed further accurately. In addition, the variance decomposition method can also reveal the fluctuating effects of a variable on itself and on shocks to other variables. For detailed analysis, we set an observation period of 20 periods and performed variance decomposition. The results of the variance decomposition are shown in Table 1.

Table 1 Results of variance decomposition

	length	ggdp_d1	co2_d1	solid_d1	coal_d1	oil_d1	gas_d1
Energy Inefficient Zone	1	1.000	0.000	0.000	0.000	0.000	0.000
	5	0.788	0.037	0.002	0.115	0.028	0.030
	10	0.787	0.037	0.003	0.115	0.029	0.030
	15	0.787	0.037	0.003	0.115	0.029	0.030
	20	0.787	0.037	0.003	0.115	0.029	0.030
Energy Medium Efficiency Zone	1	1.000	0.000	0.000	0.000	0.000	0.000
	5	0.906	0.008	0.004	0.042	0.040	0.000
	10	0.906	0.008	0.004	0.042	0.040	0.000
	15	0.906	0.008	0.004	0.042	0.040	0.000
	20	0.906	0.008	0.004	0.042	0.040	0.000
Energy High Efficiency Zone	1	1.000	0.000	0.000	0.000	0.000	0.000
	5	0.860	0.065	0.014	0.007	0.016	0.038
	10	0.851	0.068	0.017	0.008	0.018	0.038
	15	0.851	0.068	0.017	0.008	0.018	0.038
	20	0.851	0.068	0.017	0.008	0.018	0.038

For green GDP, the contribution of its own changes gradually diminishes over time, but the fluctuations of green GDP in the three regions largely depend on their own development inertia.

In the Energy Inefficient Zone, the degree of influence of electricity and coal consumption on green GDP gradually increases. This indicates that in the Energy Inefficient Zone, electric coal consumption has a much greater impact on green GDP than other factors. In the Energy Medium Efficiency Zone, the fluctuation of green GDP is influenced by the consumption of electric coal and crude oil, and their contributions gradually increase. Total CO2 Clean Mechanism trading consumption and total solid waste recycling consumption contribute much less than electric coal consumption and natural gas. In the Energy High Efficiency Zone, on the other hand, the results of the variance decomposition show that the fluctuations of the endogenous variables have stabilized in the 10th period, with high stability, and the fluctuations of the green GDP are affected by the total consumption of CO2 Clean Mechanism trading, whose contribution rate gradually rises. This indicates that in the Energy High Efficiency Zone, the total CO2 Clean Mechanism Trading consumption has a much greater impact on green GDP than other factors.

5. Conclusions and policy implications

Based on the panel data of 28 provinces from 1997 to 2020, this paper examines the mechanism and the magnitude of the effects of total CO2 Clean Mechanism trading consumption, total solid waste recycling consumption, electricity and coal consumption, crude oil consumption, and natural gas consumption on the green GDP from both theoretical and empirical perspectives. It is found that the effect of each variable on green GDP has differences in different division areas.

In Energy Inefficient Zone, Medium Efficiency Zone, and High Efficiency Zone, the effect of energy consumption on green GDP in the short term shows inhibition and promotion alternately lack of stability. This means that relying only on these increases in energy consumption does not sustainably promote green economic growth. In order to achieve sustainable development, we need to take comprehensive measures, including improving CO2 Clean Mechanism trading, enhancing solid waste recycling and sustainable disposal, reducing reliance on coal for electricity, finding sustainable alternatives to crude oil, and integrating the use of natural gas resources with renewable energy. This will enable the realization of a long-term driver of green GDP and promote sustainable growth of the green economy.

In view of the above findings, the following policy recommendations are given:

In the Energy Inefficient Zone, where short-term positive impacts exist for electric coal and crude oil consumption, there's a risk of instability leading to negative effects. This necessitates a shift towards reduced dependence on electric coal and diversified clean energy sources for sustainable growth. The Medium and High Efficiency Zones should focus on reducing electric coal usage and advancing renewable energy to ensure long-term positive impacts on green GDP growth and sustainability.

Energy High Efficiency Zones should prioritize reducing crude oil consumption and fostering green energy development for sustainable green GDP growth. In areas with negative effects on natural gas consumption, diversification policies should be reinforced to reduce natural gas use while simultaneously supporting clean and renewable energy development for sustainable green GDP growth. By considering economic, environmental, and social factors, we can promote green economic development and achieve long-term sustainability.

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