

Dynamic Coordination Effect of Pollution Reduction, Carbon Reduction, and Economic Development in Anhui Province

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Abstract

K Based on the balanced panel data of environmental pollutants, carbon dioxide emissions, and regional GDP for 16 cities in Anhui Province from 2007 to 2023, which are treated as endogenous variables, the PVAR model is employed to investigate the dynamic equilibrium relationship between pollution reduction, carbon reduction, and economic development in Anhui Province. The study finds that: ① There is a long-term inertia effect in Anhui's economic development, which has formed a sustained self-growth mechanism compared to pollution reduction and carbon reduction. ② The causal relationship between economic development and environmental pollutant control mainly manifests as an inhibitory effect of environmental pollutant emissions on economic development. The impact response of water pollutants and atmospheric pollutants on economic development follows an "inverted U-shaped" curve, and economic development has a long-term promoting effect on environmental pollutants. ③ The phased decoupling between economic growth and carbon emissions is insufficient, and the impact of carbon dioxide emissions on economic growth shows an "inverted V-shaped" positive response. ④ The coordinated emissions of economic growth and pollution reduction and carbon reduction exhibit a "first inhibitory, then promotive" effect. Economic growth will inhibit the effects of pollution reduction and carbon reduction in the short term, but will turn into a positive promotive effect as time goes by, gradually shifting the relationship towards synergy. To achieve the "win-win" goal of high-quality economic development and ecological environment protection, Anhui Province needs to fully leverage the "double dividend" effect of economic development on pollution reduction and carbon reduction, and build a green, low-carbon, and circular development system through industrial structure optimization, technological innovation empowerment, and policy mechanism coordination.

Keywords

Pollution Reduction; Carbon Reduction; Economic Development; Shock Response; Anhui Province.

1. Introduction

Under the dual background of intensified global climate change and in-depth promotion of ecological civilization construction, the Third Plenary Session of the 20th CPC National Congress clearly put forward the strategic deployment of "we must improve the system of ecological civilization and promote carbon reduction, pollution reduction, green expansion and growth in a coordinated manner", which provides a fundamental basis for regional sustainable development in the new era. As an important ecological barrier of the Yangtze River Delta Urban Agglomeration and a key ecological corridor of the Yangtze River economic belt, Anhui Province shoulders the dual mission of ecological environment protection and high-quality

economic and social development. In this context, it has important theoretical value and practical significance to explore the interactive relationship between pollution reduction and carbon reduction and economic development for Anhui Province to explore the practical transformation path of "green water and green mountains are golden mountains and silver mountains", and to build an ecological civilization system with regional characteristics.

The academic research on environmental governance and economic development mainly focuses on two main lines. One is to explore the nonlinear relationship between economic growth and environmental quality based on the theoretical framework of Environmental Kuznets curve (EKC).[1,2] The second is to use econometric model to analyze the interaction mechanism of environment economy system. Xiangbo Tanget al. (2022) used the coupling coordination degree model and spatiotemporal geographically weighted regression model to explore the spatial evolution law and mechanism of the influencing factors of the synergistic effect of reducing pollution and carbon.[3] Yu Xiang et al. (2020); WeiyanYuan et al. (2022) used Tapio decoupling model to explore the relationship between economic growth and changes in total carbon emissions.[4,5,6] Existing studies have more experience on economic growth and ecological environment governance, but pay less attention to prefecture level cities. With the goal of anchoring high-quality economic development and "carbon peaking and carbon neutralization", can we deepen pollution reduction and carbon reduction with economic benefits under the premise of following economic operation, pollution control and climate collaborative governance? Multiple patterns of realizing environmental benefits, climate benefits and economic benefits through carbon emission reduction?

The possible marginal contributions of this paper are as follows: ① at present, most of the studies follow a one-way perspective, analyzing the mechanism of economic growth on environmental governance and carbon emission reduction or the mechanism of environmental governance and carbon emission reduction on economic growth. From the perspective of two-way causality, this paper brings pollution and carbon reduction and economic development into a unified framework, and deeply explores the interactive effects of the three pairs of relationships between pollution reduction, carbon reduction, pollution and carbon reduction and economic development, so as to further study the new trend of pollution and carbon reduction development in Anhui Province. ② This paper explores the relationship between regional economy and ecological environment in Anhui Province from a dynamic perspective, and fully considers the lag effect of economy, environment and climate. ③ Most of the existing literatures focus on the national, regional and provincial scales. From the perspective of prefecture level cities, this paper uses pvar model to investigate the dynamic equilibrium relationship between pollution and carbon reduction and economic development in Anhui Province Based on the balance panel of environmental pollutants, carbon dioxide and regional gross domestic product in 16 cities of Anhui Province from 2007 to 2023. The aim is to achieve a "win-win" situation between the high-quality development of regional economy and the protection of ecological environment in Anhui Province, and to give play to the "double dividend" effect of economic development driving the synergy of pollution reduction and carbon reduction.

2. Research Methodology and Design

2.1. Overview of the Study Area

Anhui Province is located in the east of China, in the middle and lower reaches of the Yangtze River and Huaihe River. The terrain is high in the South and high in the north and low in the middle. The landform types are diverse, including plains, hills and mountains. In 2023, Anhui Province achieved a GDP of 4.71 trillion yuan, with a year-on-year increase of 5.8%, and its economic aggregate ranked 10th in the country. As an important member of the integrated

development of the Yangtze River Delta, Anhui Province plays a key role in the regional coordinated development, but also faces the challenge of coordinated development of economic growth and ecological environment. In recent years, with the in-depth promotion of the "double carbon" goal and the optimization and adjustment of industrial structure, the imbalance between pollution and carbon reduction and economic development among regions in the province has become increasingly prominent. To this end, the "14th five year plan" of Anhui province clearly puts forward that we should focus on the strategic positioning of "three places and one area", comprehensively promote ecological environment protection and economic and social development, and strive to build a green low-carbon circular economy system to provide solid support for high-quality development.

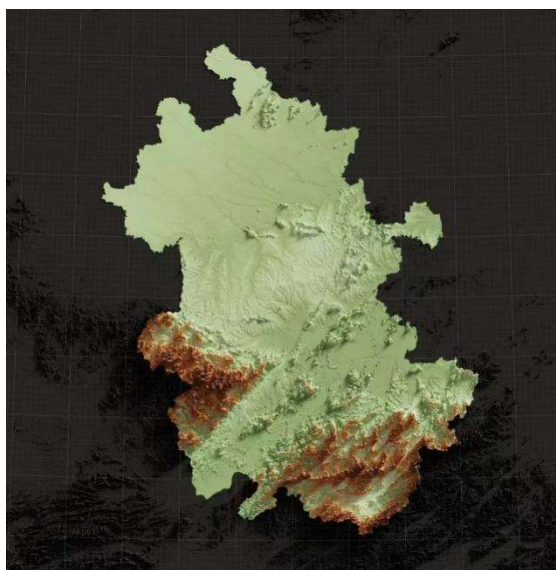


Figure 1. Geographical location of the study area

2.2. Environmental Pollutants and Carbon Emissions Accounting

Using water pollutants, air pollutants, and carbon dioxide as research objects, refer to Wu Jianxin and Guo Zhiyong (2016); The approach of Ma Yingying et al. (2024) utilizes three indicators: total wastewater discharge, SO₂ emissions, and smoke emissions.[6,7] The improved entropy weight TOPSIS method is used to construct a comprehensive index of environmental pollution, and the carbon emissions generated by electricity, gas and liquefied petroleum gas, transportation, and thermal energy consumption are added together to obtain the total carbon emissions of each city. Finally, the logarithmic value of the interaction term between the environmental pollution index and carbon emissions was calculated to obtain the equivalent emissions of pollution reduction and carbon reduction in Anhui Province from 2007 to 2023. The discharge of water pollutants is represented by the discharge of industrial wastewater, and the emission of air pollutants is referred to by Di Qianbin et al. (2025).[8] The specific improved entropy weight TOPSIS method calculation method is as follows.

Firstly, standardize the indicators.

$$x_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min x_j} \quad (1)$$

Among them, i represents the i -thevaluation object, and j represents the j -th evaluation indicator; $X = (x_{ij})_{m \times n}$ is the evaluation matrix.

Second, calculate the proportion P_{ij} of the j -th item in the i -th indicator, the information entropy e_j of the j -th indicator, and the redundancy d_j of the information entropy, respectively. The calculation formulas are as follows.

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^m x_{ij}} \tag{2}$$

$$e_j = - \frac{1}{\ln(mn)} \sum_{i=1}^m P_{ij} \ln(P_{ij}) \tag{3}$$

$$d_j = 1 - e_j \tag{4}$$

Third, determine the weights of the indicators.

$$w_j = \frac{d_j}{\sum_{j=1}^n d_j} \tag{5}$$

Among them, $w_j \in [0, 1]$, $\sum_{j=1}^n w_j = 1$

Fourth, construct the weighted normalized matrix.

$$Z = (z_{ij})_{m \times n} , z_{ij} = w_j \times x_{ij} \tag{6}$$

Fifth, determine the positive ideal solution and negative ideal solution based on the weighted normalized matrix.

$$Z^+ = \left\{ \max_{1 \leq i \leq m} z_{ij} \mid i = 1, 2, \dots, m \right\} , Z^- = \left\{ \min_{1 \leq i \leq m} z_{ij} \mid i = 1, 2, \dots, m \right\} \tag{7}$$

Sixth, calculate the Euclidean distance of each indicator to the positive ideal solution and the negative ideal solution using the following formulas.

$$D_i^+ = \sqrt{\sum_{j=1}^n (Z_{ij} - Z_j^+)^2} (i = 1, 2, \dots, m) \tag{8}$$

$$D_i^- = \sqrt{\sum_{j=1}^n (Z_{ij} - Z_j^-)^2} (i = 1, 2, \dots, m) \tag{9}$$

Seventh, calculate the closeness coefficient to the ideal solution(s) using the following formula.

$$C_i = \frac{D_i^+}{D_i^+ + D_i^-} \quad (10)$$

The closeness coefficient indicates the degree to which an evaluation object approaches the optimal solution, with a value range of $[0, 1]$. Since all selected indicators are cost-type (reverse) indicators, the evaluation criterion is defined as follows: a higher closeness coefficient represents a worse urban environmental index, and vice versa.

2.3. Data Sources and Processing

According to the research needs and referring to the existing research results, the indicators of environmental pollution, carbon emissions and economic growth are selected for statistical analysis, in order to explore the relationship between pollution and carbon reduction and regional economic development. According to the heterogeneity of pollutant emissions, water, air and CO₂ emissions were investigated respectively, and the level of economic development was measured by local gross domestic product (GDP). The synergistic effect of reducing pollution and carbon was recorded as CE. In view of the availability of data, the panel data of 16 prefecture level cities in Anhui from 2007 to 2023 were taken as samples, and the original data were logarithmically processed to generate the new variable series. In Water, In Air, In CO₂, CE and In GDP.

The indicators of environmental pollutants are from the statistical yearbook of Chinese cities from 2007 to 2023; All kinds of pollutant data, energy data and economic growth data are from the 2007-2023 China energy statistical yearbook, Anhui statistical yearbook and the statistical yearbook of cities in Anhui Province. Some index data are missing in individual years, which are supplemented by interpolation method.

2.4. Panel Vector Autoregression (PVAR) Model

The panel vector autoregressive model (pvar) not only follows the advantages of VAR model, but also optimizes the panel data. It can not only eliminate the setting of causality, but also treat each variable as an endogenous variable of the system, and any variable as a function of the lag term of other variables, but also adjust the time effect and individual effect. Impulse variance and variance decomposition were used to investigate the dynamic relationship among variables. In order to fully investigate the interactive relationship between economic growth and pollution reduction and carbon reduction, the pvar model of lnGDP and lnwater, the pvar model of lnGDP and lnair, the pvar model of lnGDP and lnco₂, and the pvar model of lnGDP and CE are established respectively. Finally, the following models are established.

$$y_{it} = \alpha_0 + \sum_{j=1}^p A_j y_{t-j} + f_i + d_t + \varepsilon_{it} \quad (11)$$

$$y_{it} = \begin{cases} \ln GDP_{it} \\ \ln Water_{it} \\ \ln Air_{it} \\ \ln CO2_{it} \\ CE_{it} \end{cases} \quad (12)$$

In the equation, y_{it} represents the five column vectors for economic development, water pollutant emissions, air pollutant emissions, carbon dioxide emissions, and synergistic

emissions of pollution reduction and carbon mitigation, y_{t-j} denotes all endogenous variables, where $i=1, 2, \dots, 16$ corresponds to the 16 cities in Anhui Province, $t=2007, 2008, \dots, 2023$ represents the years. j is the lag order of the variables, α_0 is the intercept, A_j is the regression coefficient matrix, f_i and d_t are the fixed effects and time effects, respectively, and ε_t is the random disturbance term.

3. Results and Discussion

3.1. Descriptive Statistics

The average, maximum and standard deviation of the five variables, lnwater, lnco2, CE, lngdp and lnair, are statistically described (see the table below). The standard deviation of air pollutant emissions and collaborative emissions of pollution reduction and carbon reduction in Anhui Province is relatively large, indicating that there are significant differences in the collaborative effects of air pollution control and carbon reduction among cities in Anhui Province. In contrast, the standard deviation of water pollutant emissions and regional GDP is small, indicating that the cities are relatively balanced in water pollution emissions and economic development level. In addition, the regional gross domestic product showed a steady growth trend, while the water pollutant discharge and air pollutant discharge showed a fluctuating downward trend as a whole, reflecting that while Anhui Province was growing in economy, pollutant control had achieved certain results.

Table 1. Statistical characteristics of carbon reduction and economic development variables in Anhui Province from 2007 to 2023

Variable	Definition	Obs	Mean	Median	SD	Min	Max
lnWater	Discharge of water pollutants	272	7.805	7.955	0.929	4.305	9.286
lnCO2	CO2 emissions	272	15.404	15.436	0.884	13.373	17.665
lnAir	Air pollutant emission	272	9.796	9.891	1.005	6.472	11.834
CE	Collaborative emission reduction of pollution and carbon	272	10.838	10.853	1.240	7.297	13.177
lnGDP	Gross Regional Product	272	7.027	7.007	0.773	5.054	9.447

3.2. Stationarity Tests for Pollution Reduction, Carbon Mitigation, and Economic Development

Table 2. Panel data unit root test results

Variable	LLC Test	IPS Test	ADF-Fisher Test	PP-Fishe Test	Conclusion
lnWater	-5.5021*** (0.0000)	-0.3546 (0.3614)	15.2882 (0.9945)	18.6818 (0.9706)	Unstable
ΔlnWater	-8.2748*** (0.0000)	-5.6117*** (0.0000)	103.6410*** (0.0000)	185.833*** (0.0000)	stable
lnAir	-2.7677*** (0.0028)	2.1293 (0.9834)	3.4129 (1.0000)	2.6860 (1.0000)	Unstable
ΔlnAir	-6.7936*** (0.0000)	-4.0958*** (0.0000)	70.0164*** (0.0001)	127.818*** (0.0000)	stable
lnCO2	-4.5798*** (0.0000)	-0.9840 (0.1626)	2.3860 (1.0000)	3.6898 (1.0000)	Unstable
ΔlnCO2	-5.2811*** (0.0000)	-2.8595*** (0.0021)	105.5829*** (0.0000)	289.679*** (0.0000)	stable
CE	-1.9076** (0.0282)	1.6993 (0.9554)	22.1702 (0.9028)	30.1660 (0.5596)	Unstable
ΔCE	-5.1663*** (0.0000)	-3.0824*** (0.0010)	83.8299*** (0.0000)	228.549*** (0.0000)	stable
lnGDP	-3.6567*** (0.0001)	1.2313 (0.8909)	47.2027** (0.0407)	114.1640*** (0.0000)	Unstable
ΔlnGDP	-4.1905*** (0.0000)	-1.1451 (0.1261)	32.1490 (0.4594)	120.958*** (0.0000)	stable

Using LLC test, IPS test, ADF Fisher test and PP Fisher test, the results are shown in the table below. The original sequence has unit root. After the first-order difference of the sequence, it passes the unit root test. Therefore, the pvar model can be established by the first-order difference stationary series.

3.3. Panel Cointegration Tests

Pedroni and westerlund tests were used to study the cointegration relationship among variables. The results show that all variable combinations pass the pedroni or westerlund test, and reject the original hypothesis, supporting the cointegration relationship between economic development and environmental indicators. There is reason to believe that there is a long-term equilibrium relationship between economic development, environmental governance and carbon emissions in Anhui Province.

Table 3. Panel data co-integration test results

Inspection method	Statistic type	$\Delta \ln \text{GDP}-\Delta \ln \text{Water}$	$\Delta \ln \text{GDP}-\Delta \ln \text{Air}$	$\Delta \ln \text{GDP}-\Delta \ln \text{CO}_2$	$\Delta \ln \text{GDP}-\Delta \ln \text{CE}$
Pedronit test	Phillips-Perron t	-8.1791*** (0.0000)	-7.9381*** (0.0000)	-7.3471*** (0.0000)	-7.5709*** (0.0000)
	ADF t	-7.6619*** (0.0000)	-7.0880*** (0.0000)	-6.5569*** (0.0000)	-6.9312*** (0.0000)
Westerlunt test	Gt	-1.951*** (0.000)	-1.768*** (0.001)	-2.174*** (0.000)	-2.434*** (0.000)
	Ga	-6.619*** (0.007)	-5.345* (0.087)	-9.192*** (0.000)	-9.461*** (0.000)
	Pt	-7.857*** (0.000)	-7.504*** (0.000)	-8.964*** (0.000)	-10.338*** (0.000)
	Pa	-6.574*** (0.000)	-5.487*** (0.000)	-9.655*** (0.000)	-9.822*** (0.000)

3.4. Determination of the Optimal Lag Order

The optimal lag order for the panel PVAR model of the differenced environmental-economic variables was selected based on information criteria. The results indicate that the optimal lag order is 3 for gross regional product (GRP) in relation to water pollutant emissions, air pollutant emissions, and the synergistic effect of pollution and carbon reduction, while the optimal lag order for GRP in relation to carbon dioxide emissions is 1.

Table 4. Optimal lag period of PVAR model

Variable	Lag	MAIC	MBIC	MQIC
$\Delta \ln \text{GDP}-\Delta \ln \text{Water}$	1	1.883648	-36.16216	-13.54754
	2	1.050064	-24.31381	-9.237397
	3	-1.85761	-14.53955	-7.00134
$\Delta \ln \text{GDP}-\Delta \ln \text{Air}$	1	6.979984	-31.06582	-8.451207
	2	4.748796	-20.61508	-5.538665
	3	-5.328033	-18.00997	-10.47176
$\Delta \ln \text{GDP}-\Delta \ln \text{CO}_2$	1	20.44732	-17.59849	5.016126
	2	12.43288	-12.93099	2.145417
	3	7.011699	-5.670237	1.867968
$\Delta \ln \text{GDP}-\Delta \text{CE}$	1	2.243513	-35.80229	-13.18768
	2	-0.7798366	-26.14371	-11.0673
	3	-5.294107	-17.97604	-10.43784

3.5. PVAR Model GMM Estimation Results

Based on the optimal lag order of each model, the relationship between each variable is further GMM estimated. Judging from the relationship between water pollutants and atmospheric pollutants and economic development, economic development significantly promotes sewage discharge and atmospheric pollutant emissions in the lagging period, and the subsequent lagging period will transform into a non-significant promotion effect, indicating that economic growth will significantly aggravate water pollution and atmospheric pollution in the short term, but the long-term impact will weaken. This shows that water and air pollution emissions in Anhui Province have not yet crossed the turning point and are still in the stage of "economic growth intensifies pollution". From the perspective of the relationship between coordinated emissions of pollution reduction and carbon reduction and economic development, economic growth has a continuous promotion effect on the synergistic effects of pollution reduction and carbon reduction in the first and second phases, indicating that Anhui Province's economic development and pollution reduction and carbon reduction have growth inertia and there is a self-reinforcement mechanism.

Table 5. GMM estimation of economic development and carbon reduction in Anhui Province

Variable	Dependent variable	Explanatory variable	Coefficient (P-value)	Dependent variable	Explanatory variable	Coefficient (P-value)	
ΔlnGDP-ΔlnWater	ΔlnGDP	ΔlnWater		ΔlnWater	ΔlnWater		
	L1.	ΔlnWater	-0.0714*** (0.040)	L1.	ΔlnWater	-0.1688 (0.140)	
	L2.	ΔlnWater	-0.0510 (0.126)	L2.	ΔlnWater	-0.1244 (0.116)	
	L3.	ΔlnWater	-0.0466* (0.075)	L3.	ΔlnWater	-0.0125 (0.871)	
	ΔlnGDP	ΔlnGDP		ΔlnWater	ΔlnGDP		
	L1.	ΔlnGDP	0.4048*** (0.000)	L1.	ΔlnGDP	0.5697** (0.048)	
	L2.	ΔlnGDP	0.2874** (0.011)	L2.	ΔlnGDP	0.8592*** (0.002)	
ΔlnGDP-ΔlnAir	ΔlnGDP	ΔlnAir		ΔlnAir	ΔlnAir		
	L1.	ΔlnAir	-0.0961*** (0.001)	L1.	ΔlnAir	0.1214 (0.173)	
	L2.	ΔlnAir	-0.0671** (0.013)	L2.	ΔlnAir	-0.0237 (0.744)	
	L3.	ΔlnAir	-0.0624** (0.046)	L3.	ΔlnAir	0.2843*** (0.003)	
	ΔlnGDP	ΔlnGDP		ΔlnAir	ΔlnGDP		
	L1.	ΔlnGDP	0.5261*** (0.000)	L1.	ΔlnGDP	1.1389*** (0.004)	
	L2.	ΔlnGDP	0.4622*** (0.002)	L2.	ΔlnGDP	0.0050 (0.990)	
ΔlnGDP-ΔlnCO2	ΔlnGDP	ΔlnCO2		ΔlnCO2	ΔlnCO2		
	L1.	ΔlnCO2	0.0158 (0.186)	L1.	ΔlnCO2	-0.0766 (0.103)	
	ΔlnGDP	ΔlnGDP		ΔlnCO2	ΔlnGDP		
	L1.	ΔlnGDP	0.4952*** (0.000)	L1.	ΔlnGDP	-0.3695* (0.065)	
	ΔlnGDP-ΔCE	ΔlnGDP	ΔCE		ΔCE	ΔCE	
		L1.	ΔCE	-0.0184 (0.254)	L1.	ΔCE	-0.1516 (0.138)
		L2.	ΔCE	0.0121 (0.578)	L2.	ΔCE	-0.0555 (0.455)
L3.		ΔCE	-0.0623*** (0.008)	L3.	ΔCE	-0.0764 (0.429)	
ΔlnGDP		ΔlnGDP		ΔCE	ΔlnGDP		
L1.		ΔlnGDP	0.4694*** (0.000)	L1.	ΔlnGDP	1.3158** (0.017)	
L2.		ΔlnGDP	0.2211** (0.016)	L2.	ΔlnGDP	0.6926** (0.039)	
L3.	ΔlnGDP	0.1970*** (0.002)	L3.	ΔlnGDP	0.4099 (0.153)		

3.6. Impulse Response Analysis and Variance Decomposition Analysis

The generalized method of moments (GMM) was employed to examine the lagged effects among variables. Furthermore, impulse response functions and variance decomposition analysis were applied to investigate the dynamic relationship between pollution reduction, carbon mitigation,

and economic development in Anhui Province. Through variance decomposition, the pollution reduction factors and carbon reduction factors can be disaggregated to assess the contribution of all endogenous pollution reduction and carbon mitigation variables to economic growth.

Table 6. Variance decomposition analysis

Period	Economic Development and Water Pollutant Emissions				Economic Development and Air Pollutant Emissions			
	Variance decomposition of $\Delta \ln \text{Water}$		Variance decomposition of $\Delta \ln \text{GDP}$		Variance decomposition of $\Delta \ln \text{Air}$		Variance decomposition of $\Delta \ln \text{GDP}$	
	$\Delta \ln \text{Water}$	$\Delta \ln \text{GDP}$	$\Delta \ln \text{Water}$	$\Delta \ln \text{GDP}$	$\Delta \ln \text{Air}$	$\Delta \ln \text{GDP}$	$\Delta \ln \text{Air}$	$\Delta \ln \text{GDP}$
1	1	0	0.0078	0.9922	1	0	0.002988	0.997013
2	0.966463	0.033537	0.033473	0.966527	0.915678	0.084322	0.079974	0.920026
3	0.878197	0.121803	0.049106	0.950895	0.885161	0.114839	0.156449	0.843552
4	0.773406	0.226594	0.066444	0.933557	0.839325	0.160675	0.228362	0.771638
5	0.753645	0.246356	0.073111	0.926889	0.758718	0.241282	0.29721	0.70279
6	0.737348	0.262652	0.07751	0.92249	0.719808	0.280192	0.350764	0.649236
7	0.728182	0.271818	0.080184	0.919816	0.681574	0.318427	0.397805	0.602196
8	0.726412	0.273588	0.080876	0.919124	0.654896	0.345104	0.435663	0.564337
9	0.725879	0.274121	0.081123	0.918877	0.646609	0.353391	0.465973	0.534027
10	0.725809	0.274191	0.08117	0.91883	0.641978	0.358022	0.491498	0.508502
Period	Economic Development and Carbon Dioxide Emissions				Economic Development and the Reduction of Pollution & Carbon Emissions			
	Variance decomposition of $\Delta \ln \text{CO}_2$		Variance decomposition of $\Delta \ln \text{GDP}$		Variance decomposition of ΔCE		Variance decomposition of $\Delta \ln \text{GDP}$	
	$\Delta \ln \text{CO}_2$	$\Delta \ln \text{GDP}$	$\Delta \ln \text{CO}_2$	$\Delta \ln \text{GDP}$	ΔCE	$\Delta \ln \text{GDP}$	ΔCE	$\Delta \ln \text{GDP}$
1	1	0	0.005922	0.994078	1	0	0.046799	0.953202
2	0.984392	0.015608	0.010381	0.989619	0.948076	0.051924	0.038676	0.961324
3	0.981708	0.018292	0.011	0.989	0.914258	0.085742	0.044788	0.955213
4	0.981051	0.018949	0.011144	0.988856	0.886441	0.11356	0.072519	0.927481
5	0.980898	0.019102	0.011177	0.988823	0.870587	0.129413	0.069734	0.930267
6	0.980862	0.019138	0.011185	0.988816	0.859793	0.140207	0.068197	0.931803
7	0.980854	0.019146	0.011186	0.988814	0.852595	0.147405	0.06903	0.93097
8	0.980852	0.019148	0.011187	0.988813	0.848175	0.151825	0.068831	0.931169
9	0.980851	0.019149	0.011187	0.988813	0.845289	0.154711	0.068762	0.931238
10	0.980851	0.019149	0.011187	0.988813	0.843425	0.156575	0.068762	0.931238

3.6.1. The Dynamic Relationship between Economic Development and Water Pollution Emissions

Figure 2 shows that both water pollutants and local gross domestic product respond promptly to their own unit impact. Anhui Province's economic growth exhibits a strong self-strengthening mechanism, with a rapid and sustained positive response. However, the response of water pollutant emissions to their own impact rapidly decays, indicating that economic growth has a significant inertia effect and is in line with the long-term accumulation characteristics of regional economic development. When water pollutants are impacted, economic growth shows a sustained negative inhibitory effect, indicating that water pollution may constrain the high-quality economic development of Anhui Province through resource constraints, ecological damage, or increased treatment costs. When economic growth is impacted, the response of water pollutant emissions shows a trend of "first positive and then

negative", indicating that the amount of industrial wastewater in Anhui Province increased in the early stage of economic development. With the conversion of economic momentum, optimization of energy structure, and progress in wastewater discharge technology, the amount of industrial wastewater emissions showed a negative growth, confirming the inverted "U" hypothesis of the Environmental Kuznets Curve.

In the variance decomposition of $\Delta \ln \text{Water}$, the changes in water pollutant emissions from period 1 to period 3 are almost entirely explained by their own impacts (100%). Starting from the fourth period, the contribution of economic development gradually became apparent and eventually stabilized at about 27.4%, indicating that the impact of economic development on water pollutant emissions has a lag but gradually increases; In the variance decomposition of $\Delta \ln \text{GDP}$, the impact of industrial wastewater on economic development began to emerge from the first period with a contribution of 0.78% and gradually increased over time, ultimately reaching about 8.12%. This indicates that the constraining effect of water pollutant emissions on economic growth is persistent and cumulative. To this end, Anhui Province should strengthen pollution control in key industries, optimize industrial structure to promote green transformation, strengthen water ecological restoration and water resource management, and improve environmental and economic policies. Through technological innovation and institutional optimization, the coordinated promotion of economic development and water environment governance can be achieved.

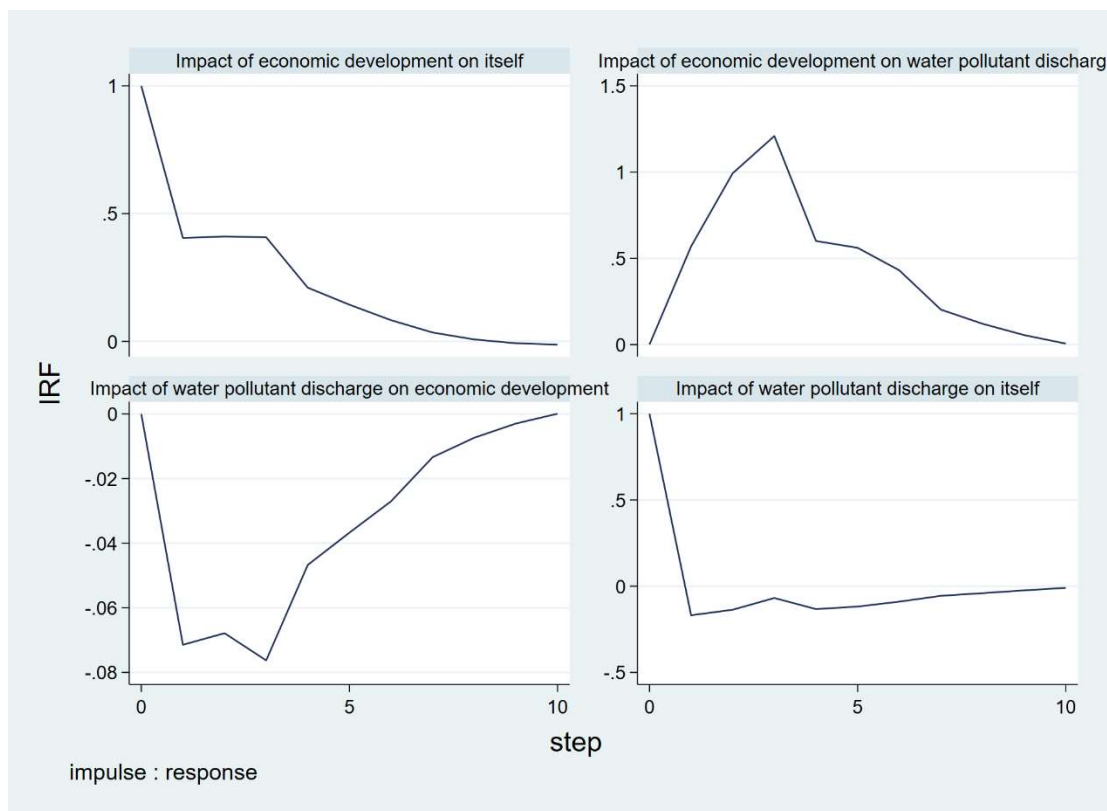


Figure 2. Impulse response curve of economic development and water pollutant discharge in Anhui Province

Note: the horizontal axis is the number of lag periods, the vertical axis is the response of variables, and the black line is the response trajectory of Anhui variables in the current period and the next 10 periods.

3.6.2. The Dynamic Relationship between Economic Development and Atmospheric Pollution Emissions

Figure 3 shows that economic development has a strong response to its own shocks, with the shock response reaching its maximum value in the current period and then rapidly declining. Compared to economic development, the self-strengthening mechanism of atmospheric pollutant emissions is weaker, and the response value continues to decline. The impact of $\Delta \ln \text{GDP}$ on $\Delta \ln \text{Air}$ shows a fluctuating response of first negative and then positive, indicating that the increase in air pollution emissions in Anhui Province in the short term will suppress economic growth, but in the long term, it may have a positive impact due to the pressure of technological upgrading or industrial transformation. The impact of $\Delta \ln \text{Air}$ on $\Delta \ln \text{GDP}$ follows an inverted U-shaped curve, showing a negative response in the current period and reaching its maximum negative value in the sixth period, indicating that the initial economic growth in Anhui Province will exacerbate air pollution. However, with the application of green technology or policy intervention, the growth rate of pollution emissions gradually slows down.

In the variance decomposition of $\Delta \ln \text{Air}$, the self-impact contribution rate gradually decreased from 100% in the first period to 64.2% in the tenth period, while the contribution rate of $\Delta \ln \text{GDP}$ increased from 0% to 35.8%, indicating that the explanatory power of economic growth on atmospheric pollution emissions has increased over time, but pollution is still mainly influenced by its own historical emissions. In the variance decomposition of $\Delta \ln \text{GDP}$, the contribution rate of atmospheric pollution increased from 0.3% in the first period to 49.1% in the tenth period, indicating that the constraining effect of pollution emissions on economic growth is gradually becoming more prominent, especially in the long run, which may affect economic growth through environmental governance costs or resource constraints.

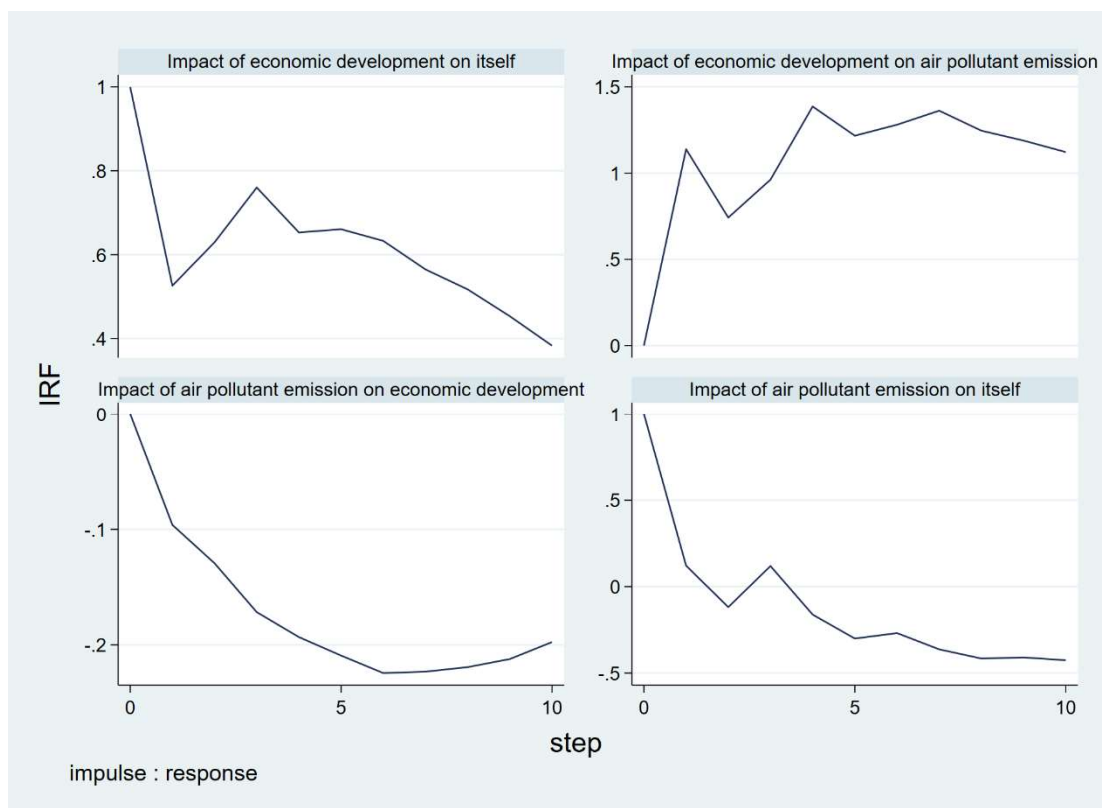


Figure 3. Impulse response curve of economic development and air pollutant emission in Anhui Province

3.6.3. The Dynamic Relationship between Economic Development and Carbon Emissions

Figure 4 shows that both $\Delta \ln CO_2$ and $\Delta \ln GDP$ reach their maximum values in the current period when facing a single unit impact, with the former having less inertia than the latter. The response of $\Delta \ln CO_2$ to the impact of $\Delta \ln GDP$ shows an inverted V-shaped curve. The economic growth in the first three periods led to an increase in carbon emissions, but the growth rate slowed down and stabilized after the third period, indicating that Anhui Province's economic growth still relies on energy consumption. However, the energy structure adjustment during the 14th Five Year Plan period may have slowed down the growth rate of carbon emissions. The response of $\Delta \ln GDP$ to the impact of $\Delta \ln CO_2$ shows a positive weakening trend, indicating that an increase in carbon emissions may promote economic growth in the short term, but the long-term impact is limited and may even inhibit economic growth due to environmental constraints. In the variance decomposition of $\Delta \ln CO_2$, the self-contribution rate decreased from 100% in the first period to 98.1% in the tenth period, while the contribution rate of economic growth only increased from 0% to 1.9%, indicating that carbon emissions in Anhui Province are mainly affected by historical emissions, and the explanatory power of economic growth is weak, indicating that the current economic development model has not completely deviated from the high carbon path. In the variance decomposition of $\Delta \ln GDP$, the contribution rate of carbon emissions decreased from 0.6% in the first period to 1.1% in the tenth period, with a very low impact, indicating that carbon emissions have a relatively small constraining effect on economic growth, which may be related to Anhui Province still being in the middle stage of industrialization and having strong energy demand rigidity.

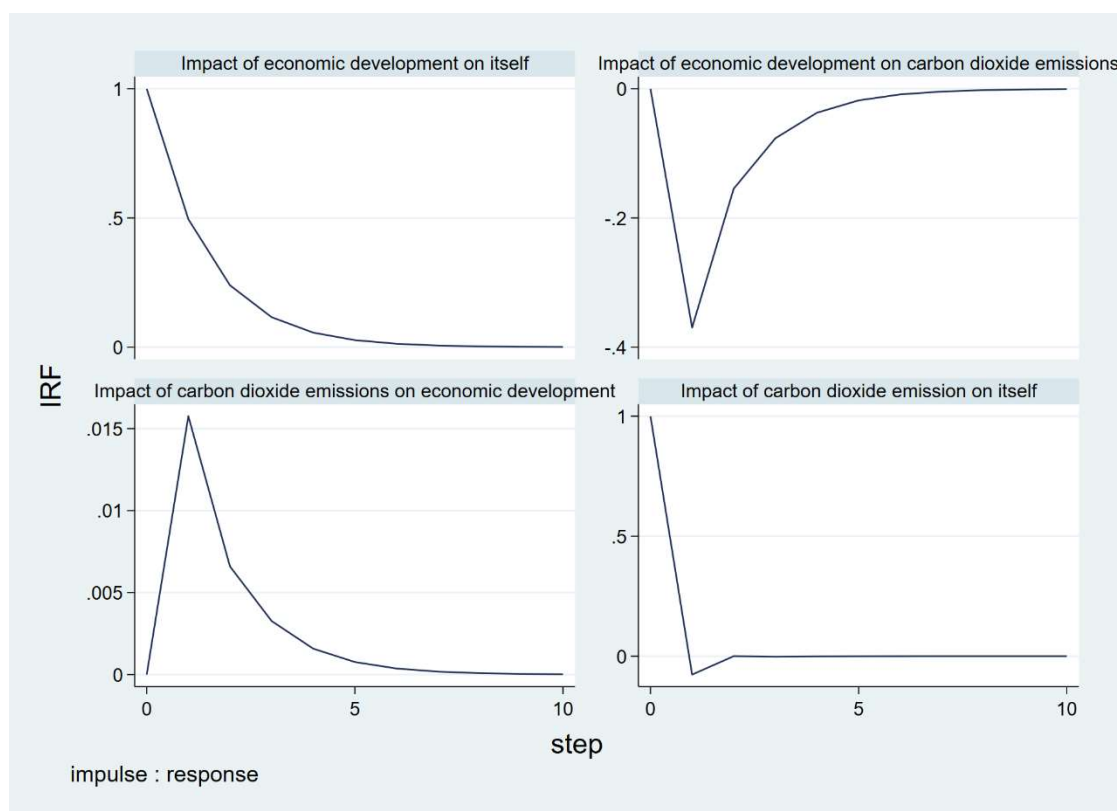


Figure 4. Impulse response curve of economic development and carbon dioxide emissions in Anhui Province

3.6.4. The Dynamic Relationship between Economic Development and Coordinated Emissions Reduction of Pollution and Carbon

Figure 5 shows that both $\Delta \ln CE$ and $\Delta \ln GDP$ reach their maximum values in the current period when facing a single unit impact, and then slowly decline. Compared to economic growth, $\Delta \ln CE$ reaches its maximum negative value in the first period, and then the negative effect shows a decreasing trend of volatility and tends to zero to remain stable. Faced with the impact of economic growth, the coordinated emissions of pollution reduction and carbon reduction show a "U-shaped" response curve, which is first negative and then positive. The current response is negative, reaching the maximum negative value in the fourth period and gradually recovering, indicating that economic growth will inhibit the effect of pollution reduction and carbon reduction in the short term, but will turn into a positive promoting effect over time. The response of $\Delta \ln GDP$ to $\Delta \ln CE$ impact reaches the maximum negative value in the current period, and then the fluctuation of the negative effect weakens, indicating that pollution reduction and carbon reduction policies will have a restraining effect on economic growth in the short term, but this effect will weaken over time.

In the variance decomposition of $\Delta \ln CE$, the self contribution rate decreased from 100% in the first period to 84.3% in the tenth period, and the contribution rate of economic growth increased from 0% to 15.7%, indicating that the pollution reduction and carbon reduction effects are mainly influenced by self policies, and the explanatory power of economic growth is gradually increasing but relatively limited. In the variance decomposition of $\Delta \ln GDP$, the contribution rate of pollution reduction and carbon reduction remains between 6.8% and 7.2%, while the contribution rate of economic growth itself remains around 93%, indicating that the impact of pollution reduction and carbon reduction policies on economic growth is relatively stable but limited.

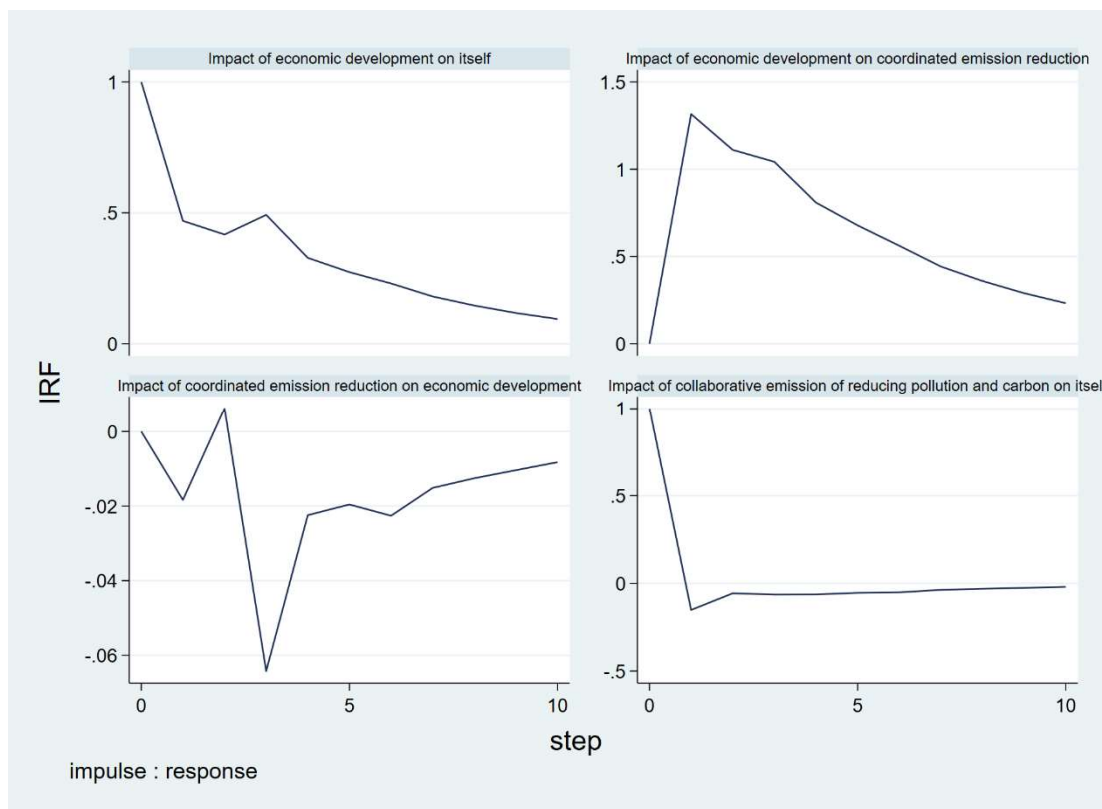


Figure 5. Impulse response curve of economic development and coordinated reduction of environmental pollution and carbon emissions in Anhui Province

4. Conclusion and Suggestions

While promoting high-quality economic development, Anhui Province is also facing the important issue of coordinating pollution reduction and carbon reduction with economic growth. This article is based on the balance panel of environmental pollutants, carbon dioxide, and regional gross domestic product in 16 cities in Anhui Province from 2007 to 2023. They are treated as endogenous variables and the PVAR model is used to examine the dynamic equilibrium relationship between pollution reduction, carbon reduction, and economic development in Anhui Province. Research has found that there is a long-term inertia effect in the economic development of Anhui Province, which has formed a sustained self-growth mechanism compared to pollution reduction and carbon reduction. The causal relationship between economic development and environmental pollutant control is mainly manifested in the inhibitory effect of environmental pollutant emissions on economic development. The impact response of water pollutants and air pollutants on economic development shows an inverted U-shaped curve, and economic development has a long-term promoting effect on environmental pollutants. The stage wise decoupling between economic growth and carbon emissions is insufficient, and carbon dioxide emissions have a "inverted V-shaped" positive response to the impact of economic growth. The synergistic effect of economic growth and pollution reduction and carbon reduction emissions shows a "first inhibition and then promotion" effect. Economic growth will inhibit the pollution reduction and carbon reduction effect in the short term, but over time it will turn into a positive promotion effect, and the relationship between the two will gradually become synergistic. Based on the above conclusions, this article has the following policy implications:

Firstly, with industrial transformation and technological innovation as the core driving force, we will focus on promoting the green transformation of traditional industries, especially the upgrading of low-carbon production processes in high energy consuming industries such as steel and cement. At the same time, actively cultivate strategic emerging industries such as new energy, energy conservation and environmental protection, and create a green industry cluster with Anhui characteristics. It is suggested to establish a provincial-level low-carbon technology research and development special fund, focusing on breakthroughs in key technologies such as renewable energy and carbon capture and utilization, building low-carbon technology demonstration parks, accelerating the transformation of green technology achievements, and providing strong technical support for industrial transformation.

Secondly, establishing a sound collaborative governance system is the key to ensuring the effectiveness of policy implementation. A collaborative control platform for carbon emissions and pollutants covering the entire province should be established to achieve real-time sharing and intelligent analysis of environmental data. Promote the linkage mechanism between carbon emission rights and environmental rights trading, and use market-oriented means to stimulate the enthusiasm of enterprises to reduce emissions. Develop differentiated environmental control policies based on the development characteristics of different regions such as northern Anhui and Yangtze River, and incorporate pollution reduction and carbon reduction indicators into the local government performance evaluation system. At the same time, establish a cross regional ecological compensation mechanism, strengthen environmental law enforcement supervision, form effective institutional constraints and incentive mechanisms, and ensure the implementation of various policy measures.

Thirdly, promoting the participation of the entire society is an important guarantee for achieving green development. On the one hand, we need to accelerate the adjustment of energy structure, strictly control the total coal consumption, increase the proportion of renewable energy generation, and promote the substitution of electricity in key areas such as industry, construction, and transportation. On the other hand, by carrying out demonstration activities

such as low-carbon cities, communities, and schools, improving green travel infrastructure, establishing carbon inclusive mechanisms, and encouraging the public to practice low-carbon lifestyles. This diversified co governance model of government guidance, corporate entities, and public participation will help create a favorable atmosphere for the whole society to jointly promote green development, ultimately achieving a synergistic win-win situation between high-quality economic development and ecological environment improvement.

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