Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2025, 12(2):314-317**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Analysis of Influencing Factors of Carbon Emissions in Henan Province Based on Multiple Linear Regression

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Abstract: This study analyzes the key influencing factors of carbon emissions in Henan Province using a multiple linear regression model based on panel data from 2010 to 2019. Six independent variables were selected: energy structure (coal consumption share), industrial structure (secondary industry share), per capita GDP, population size, urbanization rate, and energy intensity (energy consumption per unit GDP). Initial regression results revealed multicollinearity issues, which were addressed through stepwise regression. The final model retained population size and energy intensity as statistically significant variables. Results indicate that both population size (coefficient = -46.351) and energy intensity (coefficient = -20,759.659) exhibit significant negative correlations with carbon emissions, potentially attributable to carbon reduction policies, clean energy adoption, and technological advancements. The unexpected negative impact of population growth warrants interpretation within China's carbon neutrality policy framework, while other variables were excluded due to collinearity. Future research should refine variable selection to enhance model robustness. This empirical analysis provides actionable insights for low-carbon policy formulation in Henan Province.

Keywords: Carbon Emissions; Multiple Linear Regression; Influencing Factors

1. Introduction/ Background

On June 26, 2009, the United States narrowly passed the American Clean Energy and Security Act (ACES), aimed at reducing greenhouse gas emissions and decreasing reliance on foreign oil, marking a significant step in U.S. climate action [1]. Under the framework of "green recovery and climate governance" and the national mandate for achieving carbon peaking by 2030, Henan Province faces a critical task in accelerating the implementation of carbon peaking and carbon neutrality policies. This aligns with its strategic priorities during the 14th Five-Year Plan period to drive high-quality, leapfrog socioeconomic development.

As a pivotal driver for global emission reduction, economic recovery, and sustainable development, the low-carbon economy has become a dominant global trend. Major developed countries are investing heavily in low-carbon sectors to cultivate new economic growth engines, accelerate transitions, and reshape competitive landscapes [2]. For instance, in April 2009, Japan announced a 15.4 trillion yen (154 billion USD) economic stimulus package, integrating emergency measures, employment stability, and financial system reforms. Earlier, in July 2008, Japan adopted the Low-Carbon Society Action Plan, positioning low-carbon development as a long-term national goal. The plan targeted a 40-fold increase in solar power generation by 2030 and pledged to reduce greenhouse gas emissions by 60–80% by 2050, alongside establishing a certified carbon credit trading market [3]. In April 2009, Japan further released the Green Economy and Social Transformation policy draft to strengthen its green economy through emission reduction initiatives [4].

As a major energy-consuming province in China, Henan accounts for approximately 5% of the nation's total CO_2 emissions, ranking among the highest. Confronting global climate imperatives, Henan—a hub for agriculture and industry—must urgently transition toward green, low-carbon development. Located in centraleastern China with 18 prefecture-level cities, Henan has demonstrated robust economic growth over the past decade, primarily driven by its secondary industry and heavy reliance on natural resources. In 2013, the province's carbon emissions reached 202.7493 million tons of standard coal, with raw coal consumption constituting 80% of its energy mix.

2. Materials and Methods

From the perspective of current social development, factors influencing carbon emissions encompass multiple dimensions. Given divergent research objectives and methodological frameworks, scholars employ varying criteria for selecting these factors, each adopting distinct measurement approaches. Furthermore, the inherent complexity of these factors and the diversity in defining related parameters lead to heterogeneous impacts on carbon emissions. Consequently, existing studies have yet to exhaustively address all potential influencing factors.

This study integrates China's current carbon emission status and existing literature to select the following independent variables: energy structure, industrial structure, per capita GDP, population size, urbanization rate, and energy intensity. Definitions of these indicators and their data selection criteria are elaborated below.

Carbon Emissions: Refers to the average greenhouse gas emissions generated throughout the lifecycle of energy production, consumption, and disposal for various energy types.

Energy Structure: Denotes the proportional distribution of different energy sources within total energy consumption or production over a specific period or region. It comprises production structure (e.g., shares of coal, oil, and other primary energy sources in total production) and consumption structure (e.g., usage patterns and shares of energy types in total consumption). For this study, coal's share in the consumption structure is selected as the proxy for energy structure.

Industrial Structure: Represents the contribution of agriculture, industry, and services to the national economy. Given the focus on carbon emissions, this study uses the proportion of secondary industry (industrial sector) in Henan Province's GDP.

Per Capita GDP: A standard indicator of living standards, calculated as the ratio of annual gross domestic product (GDP) to the resident population at year-end. For this study, it is derived by dividing Henan Province's annual GDP by its resident population.

Population Size: Refers to the total resident population within a designated region or period. To ensure data consistency, this study adopts Henan's annual resident population.

Urbanization Rate: A key metric for urbanization level, defined as the proportion of urban population to the total population (including agricultural and non-agricultural residents). Data are sourced from Henan Statistical Yearbooks.

Energy Intensity: The ratio of total energy consumption to GDP generated over a specific period, typically expressed in tons of standard coal per 10,000 yuan. At the macro level, it reflects the relationship between primary energy use and economic output. This study calculates energy intensity as total regional energy consumption divided by GDP.

Using STATA software and data from Henan's statistical yearbooks (2010–2019), a multiple linear regression model is constructed to examine the relationships between carbon emissions and the aforementioned independent variables.

The data on Carbon Emissions (CE), Energy Structure (ES), Industrial Structure (IS), Per Capita GDP (PGDP), Population Size (PS), Urbanization Rate (UR), and Energy Intensity (EI) for Henan Province from 2010 to 2019 are presented in Table 2.

Based on the aforementioned analysis, a preliminary multiple linear regression model incorporating energy structure (ES), industrial structure (IS), per capita GDP (PGDP), population size (PS), urbanization rate (UR), and energy intensity (EI) as explanatory variables is established to examine their relationships with carbon emissions (CE). The hypothesized model is formulated as follows:

$$CE = \beta_0 + \beta_1 ES + \beta_2 IS + \beta_3 PGDP + \beta_4 PS + \beta_5 UR + \beta_6 EI + \mu_i$$

3. Results & Discussion

The results of the STATA analysis for Henan Province's 2010–2019 data are presented in Table 1.

From the model outputs, the R-squared value of 0.967 (close to 1) indicates that the multiple linear regression model explains 96.7% of the variation in carbon emissions, demonstrating strong goodness-of-fit. The F-statistic (14.872) significantly exceeds the critical value of 4.28 at the $\alpha = 0.05$ level, confirming the overall statistical significance of the linear relationship. However, the regression results remain suboptimal, suggesting potential data issues. Consequently, diagnostic tests for multicollinearity, heteroskedasticity, and autocorrelation were conducted.

The Breusch-Pagan test (executed via estat hettest) yielded a p-value > 0.05, indicating no significant heteroskedasticity; thus, robust standard errors were deemed unnecessary. Multicollinearity diagnostics revealed a mean variance inflation factor (VIF) > 10, confirming severe multicollinearity among variables. Additionally, most explanatory variables exhibited p-values > 0.05, and the Durbin-Watson (DW) statistic of 3.085 (exceeding 2.5) suggested pronounced autocorrelation in certain variables. These findings necessitate further model refinement.

Table 1: Basic Multiple Linear Regression Results

ce	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
es	.82	.742	1.11	.35	-1.54	3.181	
is	628.714	663.427	0.95	.413	-1482.608	2740.036	
pgdp	.03	.222	0.14	.901	-.677	.738	
ps	-22.423	17.746	-1.26	.296	-78.898	34.052	
ur	-368.323	1604.024	-0.23	.833	-5473.043	4736.397	
ei	-33770.679	42773.522	-0.79	.487	-169895.12	102353.76	
Constant	223727.22	209783.96	1.07	.364	-443898.97	891353.41	

Mean dependent var	18469.392	SD dependent var	1685.940
R-squared	0.967	Number of obs	10
F-test	14.872	Prob > F	0.025
Akaike crit. (AIC)	155.670	Bayesian crit. (BIC)	157.788

*** *p<.01, ** p<.05, * p<.1*

To address these issues, a stepwise regression method was applied to screen variables and eliminate those contributing to multicollinearity. The final regression results are summarized in Table 2.

Table 2: Final Stepwise Regression Results+

	(1) ce
ps	-46.351***
	(-7.380)
ei	-2.08e+04***
	(-5.111)
_cons	4.71e+05***
	(7.597)
N	10
R^2	0.939
F	53.535

***p<0.01, **p<0.05, *p<0.10

As shown in Table 2, the linear relationship between carbon emissions (CE) and the variables of population size (PS) and energy intensity (EI) is expressed as follows:

$$CE = 471062.163 - 46.351PS - 20759.659EI$$

4. Conclusion

This study selects six influencing factors of carbon emissions—energy structure, industrial structure, per capita GDP, population size, urbanization rate, and energy intensity—and employs panel data from Henan Province (2010–2019) to conduct an empirical regression analysis. During the regression analysis between these variables and carbon emissions, significant multicollinearity among the explanatory variables was detected, which violates model assumptions. After addressing autocorrelation through model correction, the final functional equation for carbon emissions was derived. The results indicate that population size (coefficient = -46.351) and energy intensity (coefficient = -20,759.659) exhibit the most statistically significant impacts on carbon emissions, both demonstrating negative linear correlations.

Contrary to conventional expectations, where larger population sizes are typically associated with increased carbon emissions, the regression outcomes and scatterplot visualization (Figure 1) reveal an inverse relationship. This anomaly may be interpreted within the context of China’s carbon peaking and neutrality policies, widespread promotion of low-carbon lifestyles, and the accelerated adoption of clean energy technologies. These factors collectively suggest that population growth in Henan Province could align with declining carbon emissions under proactive decarbonization strategies.

Variables excluded during the multicollinearity screening process (e.g., energy structure, industrial structure) may reflect inadequacies in indicator selection or measurement, necessitating further investigation. Future research should refine variable definitions and incorporate additional contextual factors to enhance model robustness and theoretical coherence.

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