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Research on the Effectiveness of Guangdong's Green Electricity Policy on Energy Structure Transformation under the Dual Carbon Goals Based on the Difference-in-differences Model

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Abstract: *Accurately identifying the actual role of Guangdong's green power policy in energy transition is of great significance for optimizing regional energy layout and facilitating the implementation of the "dual carbon" goals. Existing studies mostly assess policy effects at the provincial level, making it difficult to reveal regional heterogeneity and true net effects within the province. For this purpose, this paper takes the launch of the green electricity trading market in Guangdong in 2021 as a policy shock, selects panel data of 21 cities in Guangdong from 2016 to 2024, and conducts empirical analysis with carbon emission intensity, proportion of non-fossil energy consumption, and per capita electricity consumption as core indicators. Based on the benchmark DID model, control variables such as economy, technology, and industry were introduced, and confounding factors were stripped through stepwise regression and placebo tests to accurately identify the net effect of the policy, and regional heterogeneity tests were conducted to ensure the reliability of the research results. The results show that: (1) The launch of the green electricity trading market in Guangdong Province in 2021 has a significant positive net effect on the energy structure transformation; (2) The policy effect was robust and showed a gradient difference of "Guangzhou-Shenzhen > other Pearl River Delta > eastern, western, and northern Guangdong". Based on this, it is suggested that Guangdong improve the green power trading mechanism, implement differentiated regional policies, increase support for the eastern, western, and northern regions of Guangdong, promote the synergy of green power and carbon markets, and facilitate energy transition and the realization of the "dual carbon" goals.*

Keywords: *Difference-in-differences model; Policy evaluation; Energy structure transition; Regional heterogeneity*

1. Introduction

The continuous intensification of global warming has forced countries around the world to accelerate the green and low-carbon transformation of the energy structure. China has explicitly proposed the dual carbon goals, and the green and low-carbon transformation of the power industry has become a key support for achieving this goal. Guangdong, a major energy-consuming province, has significant differences in regional resource endowments and development levels within the province. Since the launch of the green electricity trading market in 2021, domestic policies and research have been continuously improved, while foreign research in this field started earlier and has a more mature system.

In terms of policy effect assessment, mature research paradigms have been formed abroad. Angrist (2008)[1] laid the foundation for the DID method, and Johnstone et al. (2010)[2] and Sanya Carley (2009)[3] applied it to the assessment of renewable energy policies; In China, focusing on the "dual carbon" goals, Zhang et al. (2021)[4] and Yang et al. (2025)[5] conducted research on low-carbon transformation through the DID model, while Liang et al. (2024)[6] and Nian Meng et al. (2025)[7] simultaneously identified existing problems in the green electricity market and regional policy differences. However, the existing research lacks heterogeneity analysis in the three major regions

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within Guangdong Province, and it is difficult to strip away various interfering factors, leaving research gaps. Therefore, it is practically necessary to scientifically assess the net effect of Guangdong's green electricity policy.

Based on this, this paper uses data from 21 cities in Guangdong Province from 2016 to 2024 as samples, takes the launch of the green electricity trading market in 2021 as a policy shock, and, after parallel trend tests, conducts multi-index analysis with Guangzhou-Shenzhen and other parts of the Pearl River Delta as treatment groups and eastern, western, and northern Guangdong as control groups. The study used the DID model, incorporated control variables such as economy, industry, and technology, and combined stepwise regression, placebo test, and regional test to eliminate interference. It found that the green power policy significantly promoted the transformation of the energy structure, and the effect showed a gradient difference of "Guangzhou-Shenzhen > other Pearl River Delta > eastern, western, and northern Guangdong", which can provide empirical support for Guangdong to optimize the green power policy and advance the dual carbon goals.

2. Research Method Introduction and Model Construction

2.1. Data Sources

To ensure the reliability and authority of the data, the study data in this paper were taken from official platforms and core journals such as the Bureau of Statistics of Guangdong Province, the People's Government of Guangdong Province, and the Department of Ecology and Environment of Guangdong Province.

2.2. Benchmark DID Model Set Up

2.2.1. Parallel Trend Hypothesis Testing

The parallel trend hypothesis is a core premise of the DID model. The model is applicable, and the results are reliable if the regional indicator trends are basically parallel, and there is no advance effect before the policy is implemented, and the trend is stable after the policy is implemented. Formulas are as follows:

$$y_{it} = \alpha_i + \lambda_t + \Sigma_{k=-m}^{n} \beta_k \left(Treat_i \times D_{it}^k\right) + \varepsilon_{it} \tag{1}$$

Among them, α_i and λ_t represent individual and time fixed effects, respectively; D_{it}^k is the dummy variable for each period before and after the policy; β_k is the policy effect for each period.

2.2.2. Benchmark DID Model

The benchmark DID model is a common method used in policy evaluation to identify the net effect of a policy by eliminating temporal and individual interference through differencers. Models are as follows:

$$y_{it} = \alpha + \beta Treat_i + \gamma Post_i + \delta (Treat_i \times Post_i) + \varepsilon_{it} \tag{2}$$

Among them, y_{it} is the explained variable; $Treat_i$ is the group dummy variable; $Post_i$ is the time dummy variable; $Treat_i \times Post_i$ is the core interaction term, and the coefficient δ represents the net effect of the policy; ε_{it} is the random error term.

2.3. DID Model After Stripping Confounding Factors

2.3.1. Progressive Stepwise Regression

To eliminate confounding factors and identify the net effect of regional heterogeneity, this study constructed a progressive DID model, gradually introducing control variables in four groups to eliminate the bias of omitted variables and improve estimation accuracy.

(1) Baseline model without control variables (region-wide interaction term):

$$y_{it} = \alpha_0 + \beta_1 did_{gsit} + \beta_2 d_i d_{Prdit} + \beta_3 did_{ydxbit} + \mu_i + \lambda_t + \varepsilon_{it} \tag{3}$$

Among them, y_{it} represents the dependent variable; did_{gsit} did_{Prdit}, and did_{ydxbit} are the interaction terms of the three regional policies; β_1, β_2, and β_3 are the core focus coefficients (the net effect of the three regional policies); μ_i and λ_i are the individual and time fixed effects, respectively; ε_{it} is the random disturbance term.

(2) Include the level of economic development:

$$y_{it} = \alpha_0 + \beta_1 did_{gsit} + \beta_2 d_i d_{Prdit} + \beta_3 did_{ydxbit} + \gamma_1 gdp_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

Add the actual GDP growth rate (gdp_{it}) to eliminate the influence of the economic development level.

(3) Incorporate industrial structure:

$$y_{it} = \alpha_0 + \beta_1 did_{gsit} + \beta_2 did_{Prdit} + \beta_3 did_{ydxbit} + \gamma_1 gdp_{it} + \gamma_2 ind_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

Introduce the concept of "secondary industry proportion" (ind_{it}) to further regulate the differences in industrial structure.

(4) Incorporate technological progress:

$$y_{it} = \alpha_0 + \beta_1 did_{gsit} + \beta_2 did_{Prdit} + \beta_3 did_{ydxbit} + \gamma_1 gdp_{it} + \gamma_2 ind_{it} + \gamma_3 rd_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (6)$$

Add the R&D input intensity (rd_{it}) and remove the influence of technological progress.

2.3.2. Randomly Assigned Placebo Tests

To rule out false significance caused by random factors, this study uses a randomly assigned placebo test for robustness.

First, randomly select the virtual processing group and construct the virtual policy interaction term:

$$fake\_did_{it} = fake\_treat_i \times Post_i \quad (7)$$

Among them, "$fake\_treat_i$" represents the dummy variable for the fictional treatment group. "$Post_i$": the dummy variable for the policy time.

Then substitute into a benchmark model with full variable control for regression:

$$y_{it} = \alpha_0 + \beta_{fake} fake\_did_{it} + \sum_{k=1}^{4} \gamma_k Controls_{kit} + \mu_i + \lambda_t + \varepsilon_{it} \quad (8)$$

Among them, β_{fake} represents the coefficient of the fabricated policy effect, while the other variables are consistent with the base model.

Ultimately, the regression simulation is iterated 500 cycles to construct the empirical distribution of the fictitious coefficient β_{fake}. If the fictitious effect was not significant, the benchmark results would be considered reliable and robust.

2.3.3. Region-Specific Robustness Tests

To verify the regional consistency and logical rationality of the policy effect, this study split the samples into three major regions: Guangzhou-Shenzhen, the other Pearl River Delta, and eastern, western, and northern Guangdong, and regressed respectively:

$$y_{it} = \beta_0 + \beta_1 post_{it} + \sum_{k=1}^{4} \gamma k Controls_{kit} + \mu_i + \lambda_t + \varepsilon_{it} \quad (9)$$

Among them, "$post_{it}$" is a policy time dummy variable. Its value is 1 for the years 2021 and onwards, and 0 for the years before that. β_1 represents the policy effect in this region.As long as β_1 maintains consistent directional signs, significant outcomes, and variation trends across all subsamples compared with the baseline regression; the empirical outcomes are statistically robust.

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3. Analysis of Empirical Results

3.1. Benchmark DID results

3.1.1. Parallel trend Hypothesis test results

Parallel trend tests were conducted on three core indicators in three major regions in this study. Figure 1 shows that the trends of indicators in each region were basically parallel from 2016 to 2020, with no advance effect. The trends from 2021 to 2024 were stable with no abnormal fluctuations, meeting the applicable conditions of the DID model.

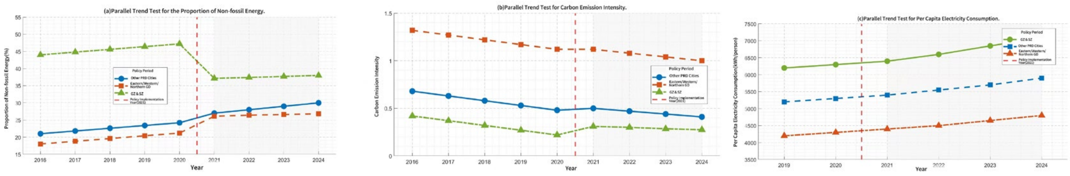


Figure 1: Results of the three-region three-indicator parallel trend test.

3.1.2. Benchmark DID model results.

The benchmark DID model results are shown in Figure 2. After the policy was implemented, the energy transition in the three major regions achieved remarkable results, and the range of indicator changes was in the eastern, western, and northern parts of Guangdong > other parts of the Pearl River Delta > Guangzhou, and Shenzhen. Eastern, western, and northern Guangdong saw the fastest growth, while Guangzhou, Shenzhen, and other cities in the Pearl River Delta still led significantly in terms of indicators.

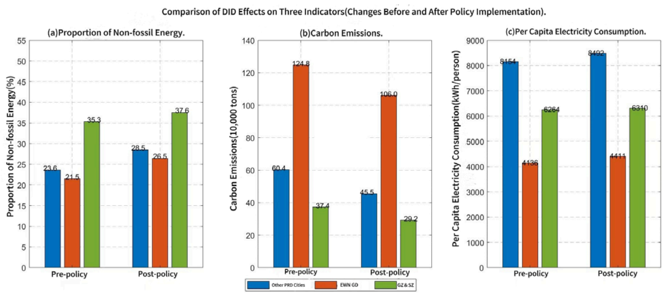
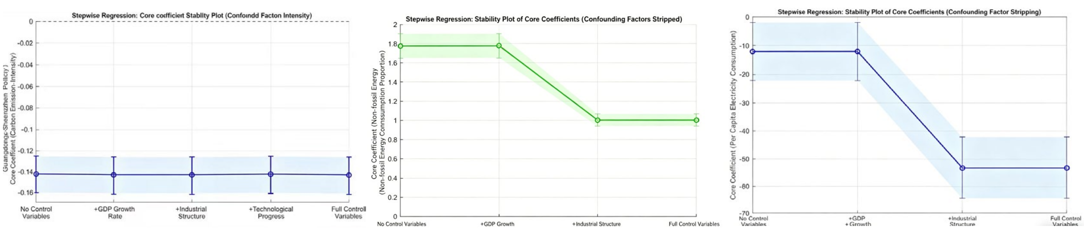


Figure 2: Analysis of DID effects in three regions and three indicators.

3.2. DID results after stripping away confounding factors

3.2.1. Progressive stepwise regression results

The progressive stepwise regression results showed that the control variables improved the model's fit. The policy effect in Guangzhou-Shenzhen was highly robust, followed by other cities in the Pearl River Delta, and not significant in eastern, western, and northern Guangdong. The results validate the regional heterogeneity of the policy. After excluding confounding factors, the regional core coefficients are shown in Figure 3.



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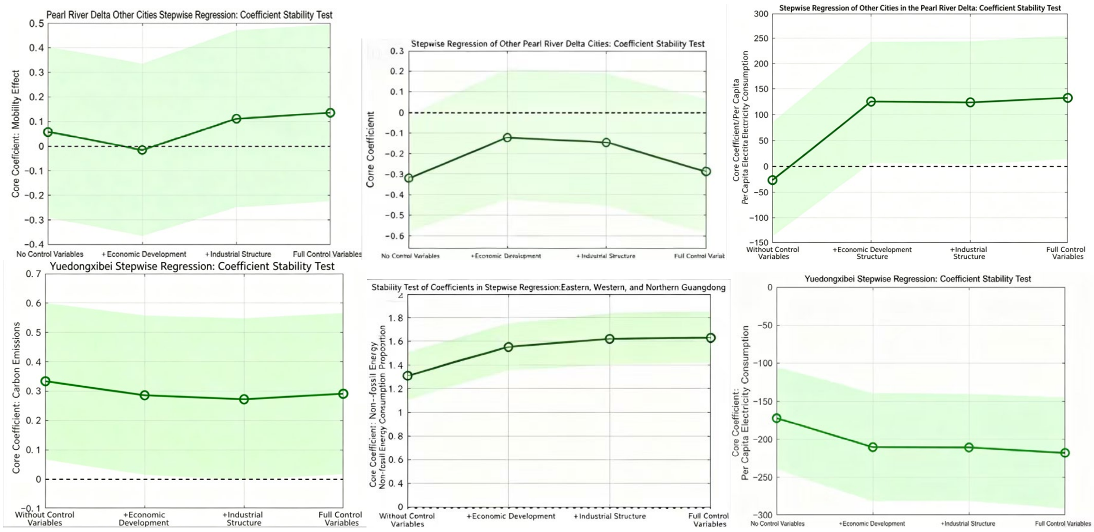

Figure 3: Results of the three-region progressive stepwise regression.

3.2.2. Randomly assign placebo test results

The results of the random placebo test are shown in Table 1. The fictional coefficients in the Guangzhou-Shenzhen, other Pearl River Delta, and the entire treatment group followed a normal distribution with a mean of 0. The true coefficient was at the tail of the distribution, and the proportion of fictional coefficients exceeding the true value was less than 2%. There was no false significance, verifying the causal validity of the policy. The regional significance gradient was consistent with the benchmark regression results.

Table 1: Summary results of randomly assigned placebo tests in each region.

Outcome Variable	Region	True Policy Coefficient	Mean of 500 Simulated Placebo Coefficients	Share of Placebo Coefficients with Absolute Value > True Coefficient	Share of Placebo Coefficients Significant at the 10% Level	Test Result
Carbon Emission Intensity	Guangzhou & Shenzhen	-0.1621	-0.0032	0.8%	3.2%	Pass
	Other PRD Cities	-0.0793	-0.0028	1.0%	3.0%	
	Full Treatment Group	-0.1025	-0.0030	0.9%	3.1%	
	Eastern/Western/Northern Guangdong (Counterfactual)	-0.0165	-0.0027	42.6%	4.8%	
Non-fossil Energy Consumption Share	Guangzhou & Shenzhen	6.245	0.0215	0.6%	2.8%	
	Other PRD Cities	3.358	0.0187	1.2%	3.0%	
	Full Treatment Group	4.126	0.0201	0.8%	2.9%	
	Eastern/Western/Northern Guangdong (Counterfactual)	0.824	0.0176	38.7%	4.5%	
Per Capita Electricity Consumption	Guangzhou & Shenzhen	412.58	5.7321	1.2%	3.0%	
	Other PRD Cities	238.74	4.2865	1.4%	3.2%	
	Full Treatment Group	287.62	5.0124	1.3%	3.1%	
	Eastern/Western/Northern Guangdong (Counterfactual)	94.15	3.8752	40.2%	4.7%	

3.2.3. Regional robustness test results

The results of the regional robustness test are presented in Table 2. Only the treatment group with active green power trading showed significant policy effects. The coefficient was significant at the 5% level for Guangzhou-Shenzhen and other cities in the Pearl River Delta, but not significant in eastern, western, and northern Guangdong ($p > 0.1$). The policy effect showed a gradient of "Guangzhou-Shenzhen > other cities in the Pearl River Delta > eastern, western, and northern Guangdong", consistent with the participation in the green power market. Excluding confounding factors, this result validates the validity of the DID results, indicating that the green power policy significantly promotes the transformation of the energy structure in Guangdong.

Table 2: Results of the regional robustness test.

Region	Explained variable	Policy shock coefficient	Robust standard error	p value	Adjust R^2
Guangzhou & Shenzhen	Per capita electricity consumption	412.58	102.36	0.0000	0.4215
	Carbon emission intensity	-0.1872	0.0325	0.0000	0.4582
	Non-fossil energy consumption share	6.245	1.027	0.0000	0.4863
Other PRD Cities	Per capita electricity consumption	238.74	98.62	0.0170	0.3574
	Carbon emission intensity	-0.0926	0.0301	0.0030	0.3826
	Non-fossil energy consumption share	3.358	0.985	0.0010	0.4015
Eastern/Western/Northern Guangdong	Per capita electricity consumption	102.36	87.54	0.2430	0.2105
	Carbon emission intensity	-0.0217	0.0258	0.4020	0.1872
	Non-fossil energy consumption share	0.872	0.863	0.3140	0.2018

4. Conclusion

This study focuses on Guangdong's green power trading policy to explore its driving effect on energy structure transformation and regional heterogeneity. Using panel data from 21 cities in Guangdong Province from 2016 to 2024 as samples, the launch of the green power trading market in 2021 was used as a quasi-natural experiment for stratified analysis by three major regions: Guangzhou-Shenzhen, other cities in the Pearl River Delta, and eastern, western, and northern Guangdong. Through parallel trend tests, progressive regression and multiple robustness tests, it was confirmed that the policy has a significant driving effect on carbon emission intensity, proportion of non-fossil energy consumption, and per capita electricity consumption, and the effect shows gradient heterogeneity of "Guangzhou-Shenzhen > other Pearl River Delta > eastern, western and northern Guangdong", effectively eliminating mixed factors and random disturbances, and accurately identifying causal relationships.

The study compensates for the deficiency of existing literature that focuses on macroeconomics and lacks intra-provincial heterogeneity analysis, reveals the impact of market activity and regional differences on policy effects, and provides empirical support for Guangdong's differentiated improvement of green power policies and the realization of dual carbon goals.

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