

Energy Transition Policy and Urban Energy Use Efficiency

—— Quasi-natural Experiment Based on New Energy Demonstration City Policy

Abstract: This study employs city-level panel data spanning from 2006 to 2021 to investigate the impact of the New Energy Demonstration City Policy on urban energy use efficiency. The findings reveal a significant positive effect of the policy on improving urban energy efficiency. Notably, the policy shows particularly strong effectiveness in industrial cities with developed secondary industries and cities with advanced technological capabilities. The analysis indicates that the policy's success in enhancing energy use efficiency is primarily driven by its promotion of urban green innovation and its imposition of financing constraints on high-polluting enterprises. Based on these results, it is recommended that the Chinese government draw insights from the construction experiences of existing new energy demonstration cities. Furthermore, expanding the scope of such initiatives and prioritizing industrial centers and technologically advanced cities can optimize policy outcomes. This approach not only supports sustainable urban development but also fosters economic growth through innovative green technologies. Leveraging the successes and lessons learned from new energy demonstration cities can contribute significantly to achieving China's environmental goals and enhancing overall urban energy efficiency across the country, thus achieving sustainable development.

Key words: New Energy Demonstration City; Differences-in-Differences; Energy Use Efficiency

1. Introduction

Climate change has become one of the most pressing issues affecting social development globally. Energy, a crucial element for human survival and progress, also shapes the future of humanity. According to Acemoglu et al. (2012), controlling the consumption of traditional energy sources, such as fossil fuels and developing renewable energy are crucial for sustainable development. Achieving this goal is a significant policy challenge for many countries. With the growing awareness of environmental protection in China and the rapid technological advancements in recent years, China has emerged as the world's largest consumer and producer of renewable energy. Despite this diversification, coal still dominated China's energy consumption, accounting for 55.3% in 2023, resulting in low energy use efficiency (Shi and Wang, 2016). As China continues to develop rapidly, environmental deterioration due to the overuse of traditional energy resources has intensified. Given the increasing pressure to pursue green development and promote harmony between humanity and nature, improving energy efficiency is an essential and necessary direction for our country's future development.

President Xi Jinping stressed in the Report to the 20th National Congress of the Communist Party of China that "We will prioritize ecological protection, conserve resources and use them efficiently, and pursue green and low-carbon development." These priorities directly address the global challenges of climate change and the energy crisis. Initially, China adopted command-and-control environmental regulation tools, such as setting environmental standards, pollutant emission limits, and technical standards. However, as market-oriented reforms deepened, marketable

pollution permits began playing a significant role (Shi and Li, 2020). With ongoing urbanization, the Demonstration City Policy has gained importance as a new approach. A green and low-carbon economy and society are crucial for high-quality development. In light of the current energy situation, in order to work actively and prudently toward reaching peak carbon emissions and carbon neutrality, the National Energy Administration announced the identification of new energy demonstration cities in 2014. This significant measure aims to accelerate the transition to a green development model. 81 cities and 8 industrial districts including the Changping District of Beijing, have been selected as new demonstration areas.

The New Energy Demonstration City Policy mandates that demonstration cities innovate in new energy exploitation and develop comprehensive utilization models that coordinate renewable and conventional energy sources to gradually achieve green transition. And green innovation is crucial in this process. For instance, Yangzhou City in Jiangsu Province is actively promoting the construction of the “Smart Valley” Industrial Park to support green transformation and related innovations. Similarly, Hefei City in Anhui Province has initiated several projects, such as the New Energy Building Group and the Comprehensive Utilization Area for agriculture and forestry energy to increase the proportion of new energy in total energy consumption. Governments in demonstration cities are also encouraged to develop suitable evaluation systems tailored to their unique characteristics to effectively promote green construction. For example, Mudanjiang City in Heilongjiang Province has creatively integrated small hydropower, wind power, and photovoltaic power, thereby providing clean energy for the entire city with its resource advantages.

Additionally, the policy requires government support for the construction of new energy demonstration cities through financial institutions. Since environmental governance typically produces positive externalities, high-polluting enterprises are often reluctant to voluntarily participate in pollution reduction efforts. Financial institutions can implement measures such as imposing financing constraints on these enterprises, compelling them to adopt green transitions.

In the "Fourteenth Five-Year Plan," the National Development and Reform Commission emphasized that non-fossil energy consumption should increase to about 20% by 2025 with continuous improvement in new energy technology. Energy use efficiency is a key indicator for sustainable and high-quality development. Evaluating the effects of energy-related policies on urban energy utilization is crucial for aiding China's green transformation. This paper examines the impact of the New Energy Demonstration City Policy on urban energy use efficiency using data from 2006 to 2021 at the urban level. The paper measures energy use efficiency through the CCR model and employs the Difference-in-Differences method to identify the policy's effect. Additionally, it explores the policy's potential mechanisms: the green innovation effect in demonstration cities and the financing constraints on high-polluting enterprises to enhance urban energy use efficiency, thereby promoting sustainable development. Heterogeneity analysis is important for further policy promotion. Building on the idea that industrial structure significantly impacts urban ecological pressure and total factor productivity (Yin et al., 2020), the paper finds that in cities with a high proportion of secondary industries, the New Energy Demonstration City Policy plays a more significant role in increasing energy efficiency. Furthermore, cities with higher technological levels see greater improvements.

In conclusion, the New Energy Demonstration City Policy improves urban energy use efficiency. This study aims to provide a basis for future policy implementation and promotion to better guide China's green transformation.

This paper makes several key contributions. First, it uniquely evaluates the New Energy Demonstration City Policy from the perspective of energy use efficiency, a novel approach in the existing literature. Second, it analyzes the policy at three levels—city, industry, and enterprise—addressing a gap in the literature, which often focuses on only a single level. Third, this paper is the first to consider the impact of financing constraints on high-polluting enterprises on urban energy use efficiency, enriching the understanding of the policy's mechanisms and providing a potential tool for governments to achieve their goals. Fourth, it offers practical suggestions and insights for the future promotion of new energy demonstration cities in China, aiding in the pursuit of green development and promoting harmony between humanity and nature.

2. Literature Review

Research on the promotion and utilization of new energy has long been a major topic. According to Li et al. (2023), the New Energy Demonstration City Policy is a comprehensive environmental regulation strategy. As cities are the primary sources of global energy consumption and carbon emissions, and as awareness of climate change's severe consequences grows, urban energy policies are increasingly important. Numerous studies have investigated demonstration city policies in various contexts. Zhuang (2020) finds that Low-carbon Cities Policies focus on reducing emissions and energy consumption in high-consumption fields. Other demonstration city policies indirectly benefit the environment, such as the Innovative City Policy, which promotes urban innovation and green technology through optimized resource allocation (Li and Yang, 2019). The Smart City Policy utilizes information technology to improve urban governance and explore new models (Shi et al., 2018).

However, these policies do not specifically address energy transformation. Thus, constructing new energy demonstration cities is crucial for addressing the energy crisis. Previous studies have explored the effects of the New Energy Demonstration City Policy on various urban elements. For example, Wang et al. (2022) found that these cities significantly enhance urban land use efficiency and influence surrounding areas through spillover effects. The policy also positively impacts environmental governance, reducing wastewater and exhaust emissions (Lu and Wang, 2019; Yang et al., 2021). Moreover, the policy's impact on green innovation has been highlighted. Li et al. (2023) showed that the policy promotes urban green innovation by encouraging local governments to support corporate innovation. Similarly, Li and Zhang (2023) found that the policy fosters low-carbon development through financial subsidies and compels traditional energy-reliant enterprises to transition. This suggests that financial institutions could play a role in promoting sustainable development by restricting high-polluting enterprises. Additionally, the policy has been shown to significantly reduce carbon emissions and facilitate energy transformation (Lin et al., 2024). Overall, the New Energy Demonstration City Policy is essential for advancing green development and addressing the energy crisis through urban-level interventions and innovations.

The energy crisis and climate change are globally pressing issues, with the transformation and upgrading of the energy structure being a major concern in China. Numerous studies have explored how to improve energy use efficiency to address these challenges. Feng et al. (2023) suggested that the construction of new types of cities has hindered the increase in energy use efficiency, implying that urbanization should be tailored to the specific characteristics of each city. Additionally, Chen and Chen (2019) analyzed the heterogeneity of energy efficiency and the factors affecting it, uncovering potential problems with energy-saving policies. In terms of the relationship between

environmental regulation and energy use efficiency, most researchers support the "promotion theory," with the most notable being the "Porter Hypothesis." This theory suggests that environmental regulation can promote technological innovation and improve corporate productivity, thereby increasing energy use efficiency (Porter and Linde, 1995). Existing research also supports this theory, finding that environmental regulation policies can compel enterprises to increase R&D expenditure (Jiang, 2015; Milani, 2017).

Various studies have examined the effects of different types of demonstration cities, contributing to solving environmental problems from different angles. However, no previous studies have combined the New Energy Demonstration City Policy with energy efficiency. The former is a crucial policy in the process of green transformation, while the latter is a key indicator of energy consumption. Therefore, this paper seeks to bridge this gap by evaluating the impact of the New Energy Demonstration City Policy on urban energy use efficiency.

3. Methodology

3.1 Sample selection and data collection

Since the development and utilization of renewable energy plays an important role in responding to issues like resource constraints and energy crisis, in order to comprehensively optimize the energy structure and establish suitable energy utilization system, the National Energy Administration officially released the list of new energy demonstration cities in 2014. The aim is to comprehensively optimize the energy structure and establish a suitable energy utilization system. By examining these demonstration cities, we can gain insights into the effectiveness of renewable energy applications and their impact on reducing fossil fuel dependence. This study will contribute to understanding how new energy policies can facilitate green transformation and improve energy efficiency.

For this study, the new energy demonstration cities are identified based on the 2014 announcement. Using 2014 as the benchmark year, we will analyze data on structural and economic characteristics from 2006 to 2021. This data will be sourced from the China City Statistical Yearbook, China Statistical Yearbook for Regional Economy, and the Chinese Statistics Yearbook. Observations with incomplete data will be excluded from the analysis to ensure robustness and accuracy.

3.2 Variable definition and data description

In this paper, the key explained variable is urban energy use efficiency. Drawing from the methodology of Shi and Li, (2020), using the CCR model (Charnes-Cooper-Rhodes model) to measure it. Following the approach outlined by Liu et al. (2017), Li and An (2012), select labor, capital and energy as inputs, while GDP as the desirable output. Industrial pollution emissions and wastewater will be considered as undesirable output. These variables will be utilized to construct a production function to estimate the marginal impact of energy input on the economy. Subsequently, these results will be used to measure urban energy use efficiency.

This paper employs the Difference-In-Differences method to estimate the effect of the New Energy Demonstration City Policy on urban energy use efficiency. So the demonstration cities will be taken as the treatment group and the other cities will be taken as the control group. The sample time interval was divided into two sub-intervals: before the release of the policy (2006-2013) and after its release (2014-2021). Furthermore, The subscripts i and t represent the city i and the year t respectively and the definition of variables is as follows:

The explained variable $energye_{it}$ is the variable measuring urban energy use efficiency by CCR model. The $treat_{it}$ is regional dummy variable that is to 1 for the treatment group and 0 otherwise. And $post_{it}$ is the time dummy variable, which is set to 1 for the years after the release of policy and 0 otherwise. In terms of the control variable, this paper select several urban characteristics according to the basic requirement of new energy demonstration cities and previous studies. Per capita GDP ($lpergdp$) is used to represent the level of economic development; population density ($popud$) reflects the basic characteristics of city; industrial structure ($stru$) based on the proportion of the population working in the second industry, whih represents the characteristics of the overall industrial structure; the level of energetic industries ($energyp$) indicates the development scale of the energy industry; manufacturing structure ($manu$) measured by natural logarithm of the number of large enterprises; R&D investment ($tech$), financial status (fin), urban education level (edu), total urban telecommunications business (dig), total energy consumption (eu), and intensity of pollution control (er).

The main descriptive statistics of each variable are shown in Table 1. The average value of the energy use efficiency ($energye$) is 0.549 with a standard deviation of 0.164. The minimum and maximum values are 0.0407 and 2.510, respectively. This variation indicates significant differences in energy efficiency across the sample period, providing a basis for subsequent research. Similarly, the total energy consumption (eu) shows substantial differences, indicating variability in energy use among cities.

Table 1 Descriptive Statistics

VARIABLES	(1)	(2)	(3)	(4)	(5)
	N	mean	sd	min	max
$energye$	4,402	0.549	0.164	0.0407	2.510
$lpergdp$	4,402	10.50	0.720	4.595	13.06
$popud$	4,402	0.0365	0.0696	0.000351	0.901
$stru$	4,402	43.38	14.03	4.460	84.40
$energyp$	4,402	0.0264	0.0177	0.000526	0.689
$manu$	4,402	6.571	1.115	2.944	9.841
$tech$	4,402	0.0153	0.0159	0.000271	0.207
fin	4,402	16.17	1.313	12.66	20.60
edu	4,402	1.386	1.112	0	4.533
dig	4,402	12.08	1.426	2.565	16.45
eu	4,402	11.45	1.011	3.045	15.44
er	4,400	13.04	2.145	0	24.68

There are several notable differences between new energy demonstration cities and non-demonstration cities. By marking non-demonstration cities as 1 and demonstration cities as 2, and performing a mean difference test on these two sets of data, we can initially assess the policy's impact on urban energy use efficiency. The results of this test are shown in Table 2. The explained variable ($energye$) has a mean value of 0.545 in non-demonstration cities and 0.625 in new energy demonstration cities. The higher value in demonstration cities is statistically significant at the 1% level, indicating that these cities tend to have better energy use efficiency.

Table 2

Mean Difference Test (1)

Variables	Mean1	Mean2	MeanDiff
<i>energye</i>	0.545	0.605	-0.060***
<i>lpergdp</i>	10.46	11.13	-0.677***
<i>popud</i>	0.0340	0.0740	-0.040***
<i>stru</i>	43.05	48.51	-5.457***
<i>energyp</i>	0.0270	0.0200	0.007***
<i>manu</i>	6.529	7.232	-0.703***
<i>tech</i>	0.0140	0.0290	-0.015***
<i>fin</i>	16.08	17.47	-1.384***
<i>edu</i>	1.338	2.130	-0.792***
<i>dig</i>	12.05	12.56	-0.513***
<i>eu</i>	11.41	12.09	-0.676***
<i>er</i>	12.99	13.86	-0.865***

Notes: Standard errors clustered at the city level: ***p < 0.01, **p < 0.05, *p < 0.1.

Additionally, to examine changes combining with the release of the policy, this paper marks the years before 2014 as 0 and the years after 2014 as 1, then perform a mean difference test. The results, shown in Table 3, indicate no significant difference in urban energy use efficiency between the two types of cities before 2014. However, after 2014, the control group's urban energy use efficiency is significantly lower than that of the treatment group. This result preliminarily suggests that the New Energy Demonstration City Policy has positively impacted urban energy use efficiency, providing a basis for further analysis. In summary, the initial mean difference tests reveal that new energy demonstration cities have higher energy use efficiency compared to non-demonstration cities, especially after the implementation of the policy in 2014. This indicates a potential positive impact of the policy on improving urban energy use efficiency, warranting more detailed analysis.

Table 3

Mean Difference Test (2)

Variables	Period=0			Period=1		
	Mean1	Mean2	MeanDiff	Mean1	Mean2	MeanDiff
<i>energye</i>	0.518	0.506	0.012	0.577	0.605	-0.028**

3.3 Model setting

As a quasi -natural experiment, this paper adopt the DID method to identify the effect of New Energy Demonstration City Policy on urban energy use efficiency. This method divides the research sample into the treatment group (region with policy implementation) and control group (areas that are not implemented) to effectively explore the policy treatment effects. In addition, the did_{it} is defined as $treat_{it} * post_{it}$, the benchmark regression equation is as follow:

$$energye_{it} = \beta_0 + \beta_1 did_{it} + \beta_2 control_{it} + \mu_i + \delta_t + \epsilon_{it} \quad (1)$$

All of the control variables are organized into the matrix $control_{it}$ to be included in the regression equation and the μ_i represents the city individual fixed effect, δ_t represents the year fixed effect, and ϵ_{it} is the random error term. This regression analysis uses the city-level Cluster Standard Errors. In the benchmark analysis, the coefficient β_1 is the the focus of attention here. This

coefficient reflects the impact of policy on urban energy use efficiency. If β_1 is significantly positive, it indicates that policy can help improve the efficiency of urban energy utilization.

4. Results

4.1 benchmark Regression

4.1.1 Main Results

This paper uses the above benchmark regression model to explore the effect of the New Energy Demonstration City Policy on urban energy use efficiency, the main results are shown in Table 4. This table presents the results that including only interactions without any control variables (column 1), and then we add some basic socioeconomic control variables (*lpergdp*, *popud*) in column 2, and then interactions with more control variables that indirectly relate to environmental characteristics (*stru*, *manu*, *tech*, *fin*, *edu*, *dig*) in column 3, finally add all indicators in column 4 and use its result as our benchmark result.

The coefficients of the interaction terms are consistently positive and significant at the 5% level across all columns, indicating that the policy improves urban energy efficiency. This paper primarily focuses on the result in column 4, considered the benchmark result. The coefficient of *did_{it}* is 0.0425, which is significant at the 5% level. This finding suggests that the New Energy Demonstration City Policy significantly enhanced urban energy use efficiency in demonstration cities. Compared to non-demonstration cities, the energy efficiency of demonstration cities increased by 4.25%. The policy's objective is to promote sustainable development. It includes various incentives to encourage the use of renewable energy, reducing the reliance on traditional energy sources. Manufacturers are incentivized to adopt innovative equipment and techniques to produce more services or products with less energy consumption, thereby increasing energy use efficiency. Moreover, the government is expected to provide financial support for developing new energy technologies, encouraging enterprises and research institutions to invest in this area and its promotion, which further enhances efficiency when more efficient technologies are widely used. Additionally, to meet the environmental goals set by the policy, governments may impose mandatory restrictions on high-polluting enterprises, compelling them to replace outdated equipment with cleaner alternatives. This enforcement drives the transformation of their energy structures, promoting greener energy utilization. Thus, through a combination of incentives and regulatory constraints, the energy efficiency of new energy demonstration cities has been successfully improved. The policy not only encourages sustainable practices but also imposes necessary restrictions to ensure high-polluting enterprises comply with the new standards, thereby achieving the dual goals of enhancing energy efficiency and promoting environmental sustainability.

Table 4

Main Results

VARIABLES	(1) <i>energye</i>	(2) <i>energye</i>	(3) <i>energye</i>	(4) <i>energye</i>
<i>did</i>	0.0405** (0.017)	0.0390** (0.018)	0.0420** (0.017)	0.0425** (0.017)
<i>lpergdp</i>		0.0106 (0.015)	0.0564*** (0.017)	0.0625*** (0.017)
<i>popud</i>		-0.8190 (0.792)	-0.8123 (0.731)	-0.8362 (0.709)

<i>stru</i>		-0.0030***	-0.0029***
		(0.001)	(0.001)
<i>manu</i>		-0.0367***	-0.0357***
		(0.014)	(0.014)
<i>tech</i>		0.3802	0.4091
		(0.271)	(0.270)
<i>edu</i>		-0.0188**	0.0055
		(0.009)	(0.020)
<i>fin</i>		0.0055	-0.0195**
		(0.020)	(0.009)
<i>dig</i>		-0.0045	-0.0051
		(0.005)	(0.005)
<i>energyp</i>			0.5029*
			(0.275)
<i>eu</i>			-0.0104
			(0.008)
<i>er</i>			-0.0042
			(0.004)
Constant	0.5462***	0.4645***	0.3415
	(0.001)	(0.160)	(0.325)
			(0.328)
City FE	YES	YES	YES
Year FE	YES	YES	YES
Observations	4,402	4,402	4,402
R-squared	0.008	0.653	0.666
			0.669

Notes: Standard errors clustered at the city level: ***p < 0.01, **p < 0.05, *p < 0.1.

4.1.2 Parallel Trend Test

The parallel trend assumption is the basic premise for using the Difference-In-Differences (DID) method to identify the net effect of policies. This assumption requires that the treatment group and the control group exhibit the same dynamic trend before the policy implementation. If this assumption is not met, the results obtained by the DID method will be unconvincing. Therefore, this paper employs the event-study method to test the parallel trend hypothesis beforehand, and uses the results to infer whether the parallel trend assumption holds. If the parallel trend between two groups is broken after the policy implementation, it means that the energy use efficiency of the demonstration city has undergone a change relative to the non-demonstration city, which supports our result. The following model is constructed for the parallel trend test:

$$Event_{it} = \alpha + \sum_{t=8}^7 \beta_t treat_i \cdot year_t + \gamma_i + \lambda_t + \varepsilon_{it} \quad (2)$$

The $year_t$ represents the year dummy variable, calculated as the year minus 2014, equaling t . The $treat_i$ is the treatment group dummy variable, set to 1 for cities in the treatment group and 0 for the remaining cities. The definitions of other variables remain the same as previously described. This paper drops the -1 period (2013) to avoid collinearity problems. The results of the parallel trend test are illustrated in Figure 1. Before the implementation of the policy, the coefficients of the interaction terms are not significant (the 95% confidence interval contains the value 0). This

indicates that there was no significant difference in urban energy use efficiency between the treatment group and the control group before the New Energy Demonstration City Policy was implemented, suggesting that the research passes the ex-ante parallel trend test. Consequently, we can infer that the parallel trend assumption holds for all years in the sample period. After the policy was introduced, its impact gradually increased, leading to observable differences in urban energy use efficiency. With the exception of the second year post-implementation, the 95% confidence interval of the interaction coefficients did not contain the value 0, indicating significant effects. This trend persisted until the end of the sample period. These findings demonstrate that the policy has had a positive impact on increasing energy efficiency, with its effect becoming more pronounced over time. The parallel trend test confirms that the New Energy Demonstration City Policy has significantly improved urban energy use efficiency, and this indicates that this study can use the DID method to explore the policy effect.

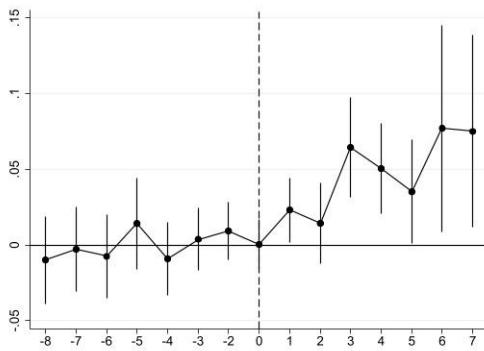


Figure1 parallel trend test result

4.2 Robustness Test

The results of DID identification is based on a series of premises and assumptions. In order to further ensure the robustness of the benchmark regression results, this paper uses a series of different methods to conduct robustness tests.

4.2.1 Permutation Test

To ensure the robustness of the results and mitigate the influence of unknown factors or omitted variables, a permutation test was conducted. This involved randomly selecting 81 cities to create a virtual treatment group 1,000 times, with the remaining cities serving as the control group. The Difference-in-Differences (DID) method was then applied to each sample to estimate the policy's effect on energy efficiency. Figure 2 displays the kernel density plot of the coefficients of the interactions and the corresponding t-values. The majority of the estimated coefficients are centered around 0, with most values within the range of 0.025. This is significantly smaller than the benchmark regression result of 0.0425. Additionally, the absolute values of the t-values for these coefficients are within 2, consistent with the expectations of the permutation test. These findings indicate that the New Energy Demonstration City Policy did not have a significant impact on the urban energy use efficiency of the virtual treatment groups in the 1,000 samples. The permutation test effectively rules out the possibility that other unknown factors interfered with the results, reinforcing the conclusion that the policy had a genuine effect on improving energy use efficiency in the actual treatment group.

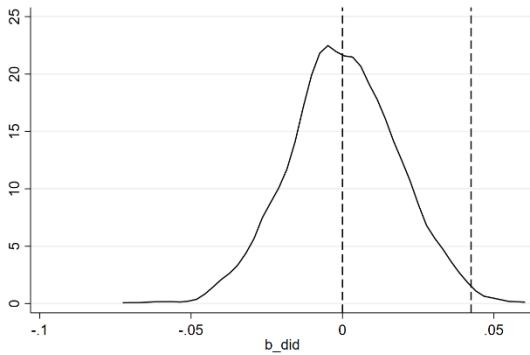


Figure2 Permutation Test results (1)

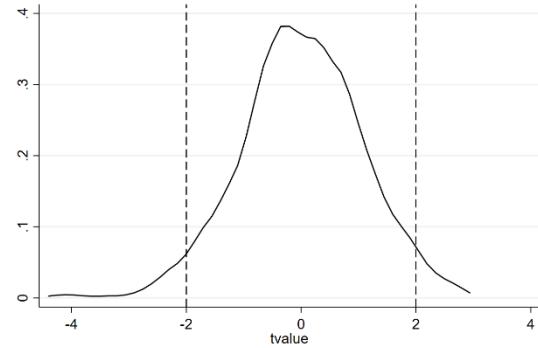


Figure3 Permutation Test results (2)

4.2.2 Synthetic DID

Policies often exhibit preferences when selecting cities, potentially leading to structural differences between the treatment and control groups. This could result in higher urban energy efficiency in the treatment group, making it unclear if the observed improvements are due to the policy or pre-existing differences. To address this, we employ the Synthetic Difference-in-Differences (Synthetic DID) method as a robustness test. The Synthetic DID method involves matching each city in the treatment group with a city from the control group that has similar characteristics prior to the policy implementation. Using these matched cities, we create a synthetic control group that closely mirrors the treatment group. Then apply the DID method to identify the effects of the policy between the synthetic control group and the treatment group. This comparison allows us to isolate the policy's impact on urban energy use efficiency.

The results of this analysis are shown in Figure 4. The figure illustrates that the energy use efficiency of both groups exhibited almost identical dynamic trends before the policy was implemented. Significant differences began to emerge one year after the policy's implementation, with these differences persisting and becoming more significant over time. Specifically, the urban energy efficiency of the treatment group is higher than that of the synthetic control group, and the rate of increase was also more substantial. These findings suggest that, even when accounting for similar structural characteristics, the treatment group's energy efficiency significantly diverged from that of the synthetic control group due to the policy implementation. This divergence indicates that the improvements in energy efficiency can indeed be attributed to the New Energy Demonstration City Policy, rather than pre-existing structural differences between demonstration and non-demonstration cities. The Synthetic DID results confirm that the possible structural differences between demonstration cities and non-demonstration cities do not affect the robustness of the benchmark regression's estimation results. This robustness test reaffirms the validity of the policy's positive impact on urban energy use efficiency.

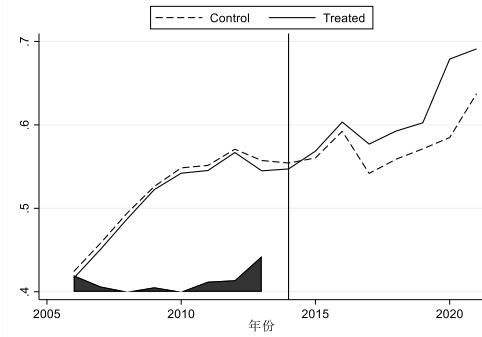


Figure4 Synthetic DID results

4.2.3 PSM-DID

Since the selection of new energy demonstration cities is not a real natural experiment, there is a potential issue of selection bias when using the DID method. This means that the treatment group and control group may not have identical characteristics in all respects before the policy implementation. To address this, we employ the Propensity Score Matching-Difference-in-Differences (PSM-DID) method for robustness testing. First, we use the PSM method to match the treatment and control groups based on all relevant features of the samples. We perform logistic regression to calculate propensity scores and match each sample with two nearest neighbors. This matching process removes samples that cannot be successfully matched, thereby eliminating unique structural characteristics that could bias the results. Next, we apply the DID method to re-estimate the results of the benchmark regression using the matched samples. The results are presented in column 1 of Table 5. The coefficient of the interaction remains positive and significant at the 5% level, indicating that the New Energy Demonstration City Policy continues to significantly improve urban energy use efficiency even after accounting for potential selection bias. This robustness test helps address concerns about the influence of pre-existing structural differences between the treatment and control groups. By matching samples with similar characteristics before the policy implementation, we reduce the bias introduced by these differences. Consequently, the results confirm that the policy's positive impact on urban energy efficiency is not driven by the unique characteristics of certain samples but is indeed a result of the policy intervention.

4.2.4 Winsorize

Winsorizing is a widely used data processing method that helps remove extreme values from datasets to eliminate bias caused by outliers. In this study, some new energy demonstration cities may exhibit extremely high energy use efficiency, potentially skewing the results. To address this, we apply winsorizing to retain only the values between the 1st and 99th percentiles for the variables *energye*, *lpergdp*, *popud*, *stru*, *energyp*, *manu*, *tech*, *fin*, *edu*, *dig*, *eu*, and *er*. This approach aims to minimize the influence of extreme values on the regression results, thereby enhancing the robustness of the analysis. The regression results after winsorizing are presented in column 2 of Table 5. Although the coefficient of the interaction term has declined, it remains positive and significant at the 5% level. This indicates that while extreme samples do affect the results to some extent, the core finding persists: the New Energy Demonstration City Policy significantly improves urban energy use efficiency. By reducing the impact of outliers, we confirm that the policy's positive effect on energy efficiency is robust. The winsorizing process ensures that the results are not disproportionately driven by a few extreme cases, thus providing a more accurate and reliable assessment of the policy's impact.

4.2.5 Shorten The Period

Since the sample period of this research spans from 2006 to 2021, the years 2020 and 2021 were marked by significant disruptions due to the COVID-19 pandemic. In China, many cities experienced lockdowns and restrictions, leading to dramatic changes in people's lifestyles and impacting various industries. This resulted in a potential decline in energy consumption as many manufacturing facilities were closed, and remote work reduced the need for power in office buildings. Consequently, these factors could affect urban energy use efficiency. To eliminate potential interferences from these extraordinary circumstances, we excluded data from 2020 and 2021 from our sample. This adjustment aims to ensure that the results are not skewed by the different energy consumption patterns during the pandemic. The revised regression result is shown in column

3 of Table 5. The coefficient of the interaction term remains positive and significant at the 5% level, indicating that even after removing the years affected by the COVID-19 pandemic, the core finding persists. We confirm that the observed positive effect of the policy is not driven by the unique conditions of 2020 and 2021.

4.2.6 Exclude Municipality Directly Under The Central Government

The inclusion of the 4 municipalities directly under the central government—Beijing, Tianjin, Shanghai, and Chongqing—may introduce bias into our regression results due to their unique status. These cities receive direct support and are subject to special regulations from the central government, which could result in characteristics that are not representative of other cities in China. To address this potential issue, these municipalities are removed from the regression analysis. The regression results are presented in column 4 of Table 5. The coefficient of the interaction remains positive and significant at the 5% level, indicating that the New Energy Demonstration City Policy continues to significantly improve urban energy use efficiency, even after excluding the four municipalities. We aim to ensure that the regression results are not unduly influenced by their unique characteristics and direct central government support. The persistence of significant results after this adjustment demonstrates the robustness of our findings.

4.2.7 Replace The Explained Variable

To address potential issues with the method of measuring urban energy use efficiency, according to Kong et al. (2023), we replace the explained variable with the SBM (Slack-Based Measure) model. The SBM model offers a more comprehensive measure of total factor energy use efficiency by overcoming the assumption that input and output must change proportionally. And this model effectively handles the slack problem in efficiency evaluation (Tone, 2002), allowing for more accurate efficiency assessments, especially when efficiency values exceed 1 unit. After replacing the explained variable and applying the DID method, the new results are presented in column 5 of Table 5. The coefficient of the interaction remains positive and significant at the 5% level, indicating that the policy continues to have a significant positive effect on urban energy use efficiency after switching to the SBM model.

Table 5 Robustness Test

VARIABLES	(1) PSM-DID	(2) Winsorize	(3) Shorten The Period	(4) Exclude Municipality	(5) Replace The Explained Variable
<i>did</i>	0.0388** (0.017)	0.0369** (0.016)	0.0322** (0.015)	0.0381** (0.017)	0.0416*** (0.016)
City FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Observations	4,384	4,400	3,851	4,336	4,400
R-squared	0.662	0.726	0.709	0.667	0.672

Notes: Standard errors clustered at the city level: ***p < 0.01, **p < 0.05, *p < 0.1. Each regression in the table includes all control variables in the benchmark regression. The constant and the coefficients of the control variables are omitted due to space constraints. Each regression in the table controls both the time fixed effect and the city fixed effect.

5. Mechanism Analysis

Green innovation refers to the development and application of new technologies that simultaneously promote economic growth and environmental protection. In the new energy demonstration cities, green innovation primarily involves the development and implementation of alternative clean energy sources such as solar, geothermal, and bioenergy to replace traditional fossil fuels. Several aspects highlight the role of green innovation. First, demonstration cities focus on harnessing renewable energy sources, reducing reliance on conventional energy forms, thereby improving energy efficiency. Second, the continuous development of science and technology facilitates the application of innovative solutions in energy production and consumption. This includes more efficient solar panels, advanced geothermal systems, and bioenergy technologies that convert waste into usable energy. Third, the policy provides a robust regulatory framework to support green innovation. By ensuring inventors and companies receive adequate returns through market mechanisms, the policy incentivizes investment in green technologies.

Moreover, the policy encourages financial institutions to support the development of demonstration cities by integrating energy conservation and emission reduction into financial ratings. This approach impacts the financing behavior of enterprises, particularly those with high pollution levels. Incorporating environmental criteria into financial ratings ensures that enterprises are evaluated based on their environmental performance. This can include their efforts in energy conservation, emission reductions, and overall sustainability practices. Additionally, High-polluting enterprises are often less inclined to voluntarily engage in pollution reduction. By imposing financing constraints, financial institutions and governments can compel these enterprises to adopt greener practices. This might involve higher interest rates for loans, limited access to capital, or mandatory investments in clean technology. In this way, the policy not only helps in meeting regulatory standards but also promotes a broader shift towards sustainable business practices.

5.1 Green Innovation

It is generally believed that the New Energy Demonstration City Policy impacts cities through environmental regulation and by improving the energy utilization structure. Among the mechanisms, green innovation plays a crucial role in promoting the development and widespread application of new energy technologies. The policy encourages and supports enterprises and research institutions in the city to engage in green innovation and R&D, as well as to upgrade energy infrastructure. Several studies have focused on the impact of environmental regulation on green innovation. For instance, Qi et al. (2018) used the expansion of the SO₂ Emissions Trading Policy in 2007 as a case study and found that the policy significantly induced green innovation in high-polluting industries. Similarly, Cui et al. (2018) evaluated the innovative effect of China's Carbon Emissions Trading Policy based on patents from listed companies and indicated that the policy promotes low-carbon technology innovation at the enterprise level. Additionally, more capital needs to be invested in green innovation to support transformational behavior (Johnstone et al., 2010; Huang et al., 2019), and the New Energy Demonstration City Policy provides such support. This paper builds on the research by Dong et al. (2019) and Wang et al. (2020), uses the IPC Green Inventory to obtain the number of green patent applications in each city. We use this as a primary indicator to measure green innovation. The natural logarithm of the number of green patent applications (lgp) is taken as the explained variable to employ the DID method. The result, shown in column 1 of Table 6, indicates that the coefficient of the interaction is positive and significant at the 1% level. This finding suggests that the policy has significantly increased the number of green patents in the city, thereby effectively

promoting green innovation. According to the mediating effect in causal inference (Jiang, 2022), after verifying that the policy can promote urban green innovation, it can be concluded that the policy improves urban energy use efficiency through the increase of green innovation.

5.2 Financing Constraints

The New Energy Demonstration City Policy has implemented specific green financial policies. These policies not only provide financial support for transforming the energy structure but also impose stringent financing constraints on high-polluting enterprises to restrict their traditional high-pollution development models. Referring to the research of Xu and Cui (2020), the government can apply more stringent financing constraints on heavily polluting industries to limit their reliance on traditional energy, thereby forcing them to make green transformations. This study obtained relevant data on heavily polluting listed companies from 2013 to 2019 through the CSMAR database. According to the research of Gu et al. (2020), we used the financing constraint index (FC index) as the explained variable to estimate the financing constraints faced by enterprises. A higher FC index indicates stronger financing constraints. The coefficient of the interaction estimated using the DID method is shown in column 2 of Table 6. The coefficient is positive and significant at the 5% level, indicating that the policy has significantly strengthened the financing constraints on high-polluting enterprises. When these enterprises are unable to obtain funds to continue their traditional energy-dependent development model due to financing constraints, they may choose to undergo green transformation or develop clean energy. This shift can lead to improved urban energy use efficiency.

Table 6

Mechanism Analysis

VARIABLES	(1)	(2)
	<i>lgp</i>	FC index
<i>did</i>	0.2588*** (0.084)	0.1345** (0.059)
City FE	YES	YES
Year FE	YES	YES
Observations	3,699	3,463
R-squared	0.910	0.893

Notes: Standard errors clustered at the city level: ***p < 0.01, **p < 0.05, *p < 0.1. Each regression in the table includes all control variables in the benchmark regression. The constant and the coefficients of the control variables are omitted due to space constraints. Each regression in the table controls both the time fixed effect and the city fixed effect.

6. Heterogeneity Analysis

In order to further explore the effects of the New Energy Demonstration City Policy in different types of cities, thus helping the following policy promotion and adjustment, this paper conduct heterogeneity analysis in two aspects: industrial structure and technical level.

6.1 Industrial Structure

The construction of new energy demonstration cities primarily improves urban energy use efficiency by altering the energy consumption structure. Given that different cities have various industrial structures, there are inherent variations in their energy demand and consumption, which can influence the policy's effectiveness. Generally, industries are classified into three major types: primary, secondary, and tertiary. The secondary industry mainly involves the processing and

manufacturing sectors, which use basic materials provided by nature and the primary industry for further processing. This industry includes mining, manufacturing, electricity, heat, gas and water supply, construction, and other processing and manufacturing sectors. It is evident that the secondary industry has a significant demand for energy. Therefore, improving energy efficiency in cities with a substantial secondary industry is crucial for overall green development. This paper categorizes cities based on the proportion of people employed in the secondary industry. Cities with a higher proportion of secondary industry employment are classified as industrial cities, while the remaining cities are categorized as non-industrial cities. We then employ the DID method to examine the impact of industrial structure on the effectiveness of the New Energy Demonstration City Policy. The results are shown in columns 1 and 2 of Table 7. The results indicate that the interaction coefficient in industrial cities is significant at the 1% level, suggesting that urban energy use efficiency improves after the policy implementation. In contrast, the results for non-industrial cities do not show the same trend. This indicates significant heterogeneity in the policy's impact based on industrial structure.

One possible reason is that cities with a higher proportion of secondary industry employment have a larger share of energy-intensive industries such as manufacturing. The New Energy Demonstration City Policy can directly influence these industries by encouraging them to reduce reliance on traditional fossil fuels. Before the policy's implementation, these cities prioritized rapid economic growth over sustainable development, leading to more severe energy crises. Post-implementation, industrial cities are more active in responding to the policy to achieve the required environmental goals. Additionally, industrial cities have a broader range of energy demands, making it easier to apply technologies related to renewable energy. In contrast, non-industrial cities have development models less dependent on energy consumption, resulting in less enthusiasm for responding to new energy policies.

6.2 Technological Level

New energy demonstration cities can tailor their responses to policy requirements based on their own characteristics. Consequently, differences in the technological level of cities may lead to varied resource allocations. Cities with advanced technology typically have a stronger foundation for innovation, enabling them to implement related innovations more effectively. This paper measures the technological level of cities based on the proportion of scientific expenditures in the local government's budget. Cities are then divided into two groups: technologically developed cities and technologically underdeveloped cities. We employ the DID method to examine the impact of technological level on the effectiveness of the New Energy Demonstration City Policy. The results are presented in columns 3 and 4 of Table 7.

The results show that in technologically developed cities, the interaction coefficient is positive and significant at the 5% level, whereas it is not significant in the remaining cities. This indicates that the policy has a more substantial effect in cities with advanced technologies and strong innovation foundations. Technologically developed cities generally have a better technical infrastructure and a rich talent pool, which facilitate innovative work. Additionally, the presence of renowned higher education institutions and innovative enterprises creates an environment conducive to talent development, promoting green innovation with more government support. Consequently, these cities can enhance urban energy use efficiency through the application of green innovations. Thus, significant heterogeneity in the technological level is observed among demonstration cities.

Table 7

Heterogeneity Analysis

VARIABLES	Industrial Structure		Technological Level	
	(1) industrial	(2) non-industrial	(3) developed	(4) underdeveloped
<i>did</i>	0.0538*** (0.020)	0.0401 (0.035)	0.0489** (0.019)	0.0358 (0.031)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	2,190	2,193	2,182	2,125
R-squared	0.780	0.631	0.696	0.681

Notes: Standard errors clustered at the city level: ***p < 0.01, **p < 0.05, *p < 0.1. Each regression in the table includes all control variables in the benchmark regression. The constant and the coefficients of the control variables are omitted due to space constraints. Each regression in the table controls both the time fixed effect and the city fixed effect.

7. Conclusion And Implications

This paper utilizes the CCR model from an input-output perspective to measure urban energy use efficiency based on relevant data from 2006 to 2021. The DID method is then employed to empirically analyze the effect of the New Energy Demonstration City Policy on urban energy use efficiency. The main findings of the study are as follows: First, the benchmark regression Results: The policy significantly improves urban energy use efficiency, with an estimated improvement effect of approximately 4.25 percentage points. This result remains robust after a series of robustness tests. Second, the mechanism analysis: The policy promotes the development and application of green innovations in cities. It also encourages governments to impose financing constraints on high-polluting enterprises, compelling them to embark on green transformations. These mechanisms collectively enhance energy efficiency in demonstration cities. Third, the heterogeneity analysis: On one hand, in terms of the industrial structure, the policy significantly improves energy use efficiency in industrial cities. These cities, which are more reliant on traditional energy for economic development, can more effectively change their energy consumption structures due to the policy. Additionally, the governments in these cities are more likely to respond to policy requirements because of their previous neglect of environmental protection, thereby enhancing the policy's effectiveness. From the perspective of technological level, the policy yields better results in technologically developed cities. These cities, with their higher technical levels and stronger innovation foundations, create an environment conducive to the development and application of green innovations, thereby improving urban energy use efficiency. Overall, the New Energy Demonstration City Policy improves urban energy use efficiency through fostering conditions that support green innovation and compel high-polluting enterprises to transition to greener practices. The effectiveness of the policy varies based on the industrial structure and technological level of the cities, with industrial and technologically advanced cities showing more significant improvements.

The results of this paper provide valuable guidance for the further construction and promotion of new energy demonstration cities. Based on the analysis, the following recommendations and insights are proposed: First, more cities should be designated as new energy demonstration cities to

address the crises caused by climate change and energy shortages. This expansion will encourage the adoption of renewable energy and reduce reliance on fossil fuels, thereby protecting the environment through reduced emissions and improved energy efficiency. Second, governments should summarize the experiences of existing demonstration cities and promote replicable cases to more areas. This approach will improve the efficiency of constructing new energy demonstration cities by leveraging proven strategies and practices. Third, an improved environmental supervision system is essential to ensure the full implementation of the goals set out in the new energy demonstration city plans, thereby achieving sustainable development. Besides, based on the mechanisms analyzed above, the government can take targeted measures to improve urban energy efficiency. For instance, governments should encourage cooperation between cities and enterprises to facilitate the application of new energy technologies. This can be achieved through partnerships and collaborative projects focused on green innovation. And the establishment of green financing platforms is also a good idea. Creating green financing platforms can support the green transition of high-polluting companies by imposing financing constraints and providing assistance to small and medium-sized new energy enterprises. This requires cooperation among government bodies and financial institutions. Finally, tailoring policy design to local conditions is crucial. The unique characteristics and resource endowments of each city should be considered to ensure the effective implementation and optimal results of the policy. According to the heterogeneity analysis, technologically developed cities with strong innovation foundations and industrial cities with developed secondary industries should receive focused efforts for the construction and promotion of new energy demonstration cities. These cities are likely to achieve better results from the policy. For non-industrial cities and those with underdeveloped technology, other policy measures may be needed to facilitate energy transformation. By implementing these recommendations, the New Energy Demonstration City Policy can more effectively promote urban energy use efficiency, enhance environmental protection, thus contribution to the process of pursuing green development and promoting harmony between humanity and nature.

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