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Local government intervention and energy utilization efficiency: evidence from China's NEDC policy

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Improving energy utilization efficiency is an essential way to save energy and reduce emissions. This article collects data from 3,164 samples in China and uses the SBM-DEA method to calculate energy utilization efficiency. Then, we construct the DID model based on China's New-Energy-Demonstration-City (NEDC) policy to test the impacts of local government intervention on energy utilization efficiency (EUE). The following conclusions can be drawn. Firstly, the NEDC policy can still significantly improve EUE. Secondly, heterogeneity analysis shows that the NEDC policy is beneficial for enhancing urban EUE, whether for traditional industrial bases or non-traditional industrial bases. The impact on non-traditional industrial bases is greater. The NEDC policy can significantly promote EUE in the eastern cities and high economic development areas. In contrast, its impact on EUE in the central and western cities or low economic development areas is insignificant. Finally, mechanism analysis shows that NEDC policy can promote energy utilization efficiency through industrial structure adjustment and green innovation.

KEYWORDS

the NEDC policy, energy utilization efficiency, industrial structure adjustment, local government intervention, green innovation

1 Introduction

Globally, greenhouse gas emission reduction poses a formidable challenge. China's share in global carbon emissions stands at approximately 30% according to the BP Energy Statistics Yearbook in 2021, subjecting it to immense pressure to curb these emissions. Recognizing this urgency, the Chinese government has prioritized environmental protection and is determined to achieve the ambitious "double carbon" target by 2035. Given that energy consumption is the primary driver of carbon emissions, enhancing energy utilization efficiency emerges as a paramount factor in mitigating emissions. Thus, improving energy efficiency stands as a vital means of conserving energy and minimizing environmental impact. Some policy guidance towards clean investment may be a sustainable way to reduce carbon emissions (Acemoglu et al., 2012). China has developed the largest capacity for new energy (Fang et al., 2023). Therefore, scientific evaluation of the impact of the NEDC policy on energy utilization efficiency (EUE) is of great significance for achieving green transformation and sustainable economic development.

Scholars have increasingly focused on various factors that influence EUE. Firstly, energy prices have garnered significant attention, with some researchers positing that escalating energy prices serve as a primary catalyst for enhancing energy efficiency (Martínez and Piña, 2014; Hang and Tu, 2007; Valizadeh et al., 2018; Streimikiene et al., 2008). Du et al. (2016) further contend that the surge in energy prices compels firms to prioritize improvements in EUE. Secondly, conversely, the influence of natural energy endowments on EUE is notably detrimental, underscoring the manifestation of the resource curse phenomenon (Wang et al., 2022; Wu et al., 2023; Wang and Zhou, 2022). They thought that regions with high energy endowments were prone to develop energy production. Thirdly, technology-relevant factors. Miao et al. (2018) thought that technological innovation has become the critical power driver for improving EUE. Wang (2018) also concluded that the improvement of EUE was mainly owing to new technology development. Li J. et al. (2023) concluded that artificial intelligence can save energy and improve EUE. Zhang and Fu (2022) believed accelerating technological development through technology introduction and innovation could improve EUE. Wu et al. (2020) contend that internet development can enhance green total factor energy efficiency by mitigating resource mismatches, fostering regional innovation capabilities, or spurring industrial structure upgrades. Wang and Shao (2023) discover that digital economy's positive impact on EUE is progressively intensifying, with a more pronounced effect observed in resource-based cities and central region samples. Li et al. (2024) uncover that the deployment of industrial robots fosters improved EUE. Zhang L. et al. (2022) find that while the digital economy development can directly enhance EUE, it indirectly contributes to increased carbon emissions. Fourthly, government intervention, which is thought to be complementary to market development rather than a substitute for China's energy utilization efficiency (Wang et al., 2021). Some scholars even emphasize that EUE relies on active government intervention (Geller et al., 2006; Zou et al., 2024; Helen and Lean Hooi, 2023). Chen et al. (2021) discovered that adjusting industrial structure and optimizing energy structure could positively impact EUE. Yang and Song (2019) proposed that sustainable energy development can achieve sustainable energy development by limiting resource development and reducing reliance on non-renewable energy sources. Kang et al. (2022) explored the influence of regional integration on the regional EUE disparity. Their findings suggest the existence of a U-shaped relationship between regional integration and the variation in EUE among urban agglomerations. The Green Credit Policy (GCP), marketization policy, the power sector reform, and innovative city policies are all proven to be effective in promoting energy efficiency (Huang et al., 2021; Li X. et al., 2023; Wang and Wang, 2023; Qin et al., 2024). In China, local government officials may fulfill their responsibilities to achieve economic and social goals due to the need for promotion (Li and Zhou, 2005). Therefore, exploring the relationship between local government innervation and energy utilization efficiency deserves scholars' attention.

The relationship between government intervention and energy utilization efficiency has been widely debated. The Porter hypothesis suggests that government intervention can improve EUE through innovative channels (Porter and Linde, 1995). Their viewpoints have been confirmed by lots of scholars such as Pan et al. (2019) and Ren et al. (2024b). And regarding the situation of environmental regulation in China, Wang and Feng (2014) argued that China's environmental interventions were comparatively lax, and strengthening these regulations would significantly contribute to an adequate boost in regional urban technological innovation within China. Moreover, several scholars have affirmed that environmental interventions are advantageous in enhancing EUE, both in the immediate and long-term perspectives (Ju and Ke, 2022; Yuan and Xiang, 2018; Xu and Xu, 2022). However, also some scholars contend that the impact of environmental regulations on EUE is insignificant or even its effect is inhibitory. For example, Hancevic (2016) argued that environmental intervention resulted in productivity declines and a subsequent decrease in EUE. Chen et al. (2021) thought that only with a reasonable carbon price, do enterprises have the motivation to innovate in clean production technology. Besides, the impact of environmental intervention on EUE also exhibits nonlinear characteristics. For example, Song and Han (2022) found that from 2006 to 2018, the contribution of China's environmental intervention to EUE went through a "U-shaped" process. Dzwigol et al. (2023) found a U-shaped nonlinear effect between EU countries' environmental intervention and EUE. Furthermore, Scholars divided environmental regulatory policies into the command type and the environmental legislation type. Their research revealed that varying forms of environmental intervention exhibit notably different impacts. For example, Liu et al. (2023) argued that command and control regulations significantly enhanced EUE in the majority of Chinese provinces. Guo and Yuan (2020) discovered a non-linear correlation existing between environmental legislation and EUE. Chen et al. (2020) likewise observed substantial variations in the impact of diverse environmental regulatory instruments on EUE. The imposition of environmental administrative penalties negatively impacts China's energy efficiency, whereas market-based environmental regulatory mechanisms exert a positive influence. Given the ambiguous correlation between environmental intervention and EUE, this study serves as a testament to the potential efficacy of environmental regulatory policies.

The influence of environmental intervention on EUE demonstrates notable regional and industrial variations. Lin et al. (2021) delved into the mechanisms and consequences of environmental intervention on EUE, uncovering the presence of a "pollution haven" effect in China. For enterprises with significant pollution levels, the influence of environmental intervention on EUE is negligible. Conversely, in regions abundant in resources, environmental intervention exerts a more pronounced positive impact on enhancing EUE. Chen and Gong (2017) discovered that environmental regulatory policies have minimal impact on the progression of low and medium-energy-consuming industries. However, for high energy-consuming industries, these policies possess considerable advantages. Zhu et al. (2024) revealed that the influence of environmental intervention on EUE is more pronounced in China's central and western regions. In contrast, Lin and Xu (2017) discovered that environmental intervention has had a positive and direct effect in eastern China, prompting companies to curtail their reliance on fossil fuels and enhance their utilization of clean energy sources; on the other hand, the environmental intervention has had a negative direct impact in the central and western regions, due to the "Green Paradox", with strict environmental regulations prompting energy owners to accelerate resource extraction. Song and Han (2022) identified notable regional disparities in the net effect, with environmental intervention exerting a stronger impetus for enhancing energy efficiency in more developed regions. Consequently, it is imperative to delve into the varied impacts of local government intervention across different regions.

Our paper may have the following marginal innovations. First, previous literature mainly focused on the effects of NEDC policy on environmental pollution (Wang and Ma, 2024; Yang et al., 2021; Fang et al., 2023). This work analyzes the effects of NEDC policy on EUE. Our findings provide empirical evidence for the innovation assumption hypothesis. Second, though some studies examine the effects of environmental policy on green innovation (Zhang D. et al., 2022), litter is known as the mechanism of how NEDC policy affects energy efficiency. This study further examines the mechanisms from two perspectives, green innovation and industrial structure upgrading. Third, this study also conducts a heterogeneity analysis. The results reveal that NEDC policy is more beneficial for non-traditional industrial bases, the eastern region, and high economic development areas. It can shed light on how to improve EUE in different cities.

The organization of this paper continues as follows. Section 2 outlines the research design, which includes the policy background and the econometric model design. Section 3 is the empirical results, which conduct baseline analysis and the heterogeneity analysis. Section 4 conducts the mechanism analysis. Section 5 concludes.

2 Theoretical analysis

Among the many factors that affect the development of energy utilization efficiency, new energy is a key factor that cannot be ignored. The application of new energy will release new impetus to improve EUE. From an institutional economics standpoint, efficient energy utilization in the regional economy is closely related to the establishment of institutions. The NEDC policy is conducive to breaking the traditional energy dependence model. Firstly, the innovation compensation theory argues that appropriate government intervention can motivate enterprises to engage in technological innovation (Porter and Linde, 1995), and promote sustainable development (Li Y. et al., 2023). As a kind of government intervention, NEDC policy can foster the development of new energy technology and facilitate the replacement of traditional energy sources (Wu et al., 2017). Secondly, NEDC policy offers financial and technical assistance for the transformation of energy structures and ecological environment management in pilot cities, which will necessitate enterprises to embark on green innovation initiatives (van der Schoor and Scholtens, 2015; Yu et al., 2021; Zhou et al., 2023). This will propel efficient energy utilization within these pilot regions. Therefore, the subsequent research hypothesis H1a can be formulated.

H1a: The NEDC policy can effectively improve urban energy utilization efficiency.

Conversely, the third perspective is that government intervention mainly brings about the "compliance cost". Scholars who support this view argue that government intervention has brought about additional input, leading to reduced productivity (Hancevic, 2016). Greenstone et al. (2012) also found that stricter air quality regulations have brought about almost 3% percent drop in TFP. Thus, we formulate the hypothesis H1b.

H1b: The NEDC policy will hinder urban energy utilization efficiency.

If the above positive effects are present, what mechanism does the NEDC policy improve energy utilization efficiency? The primary sources of improvement in EUE stem from industrial restructuring and advancements in technology (Song et al., 2024; Chen et al., 2023; Yang et al., 2021). Green technology is an important driving force for China to achieve green development. The NEDC policy is a green and low-carbon action driven by a technological revolution. To achieve long-term and healthy development of renewable energy, the key lies in developing new technologies and breaking through the high-cost bottlenecks that restrict the production and development of clean and renewable energy. NEDC policy can curb SO2 emissions by fostering green investment, encouraging green innovation, and ultimately, reducing energy consumption (Wang and Ma, 2024; Ren et al., 2024a). Green technology innovation can achieve high-quality and efficient operation of energy-consuming equipment by innovating production technology. Technological innovation can save relatively expensive production factors such as energy.

In addition, the NEDC policy may have an impact on the local industrial structure. In one aspect, to promote the NEDC construction, the Chinese government has released a series of management documents related to new energy. NEDC policy sets evaluation indicators such as the amount of new energy development and utilization, which will impose certain restrictions on high energy-consuming enterprises. Industrial enterprises that overly rely on traditional fossil fuels have low resource utilization efficiency (Ren et al., 2024d). Inadequate environmental protection may be forced to close or relocate to surrounding cities due to local restrictions; At the same time, some enterprises choose to transform and upgrade to seek new paths for sustainable development (Wang et al., 2024a). In another aspect, the pilot cities have generally established financial subsidies for the new energy industry, which includes the support of fiscal funds. A large influx of funds can effectively promote the application of new energy, encourage more enterprises to invest in the development of green new energy, and thus improve energy utilization efficiency (Dong et al., 2023; Ye and Yue, 2023; Wang et al., 2024b). Consequently, this article posits the following research hypotheses, aimed at the impact of NEDC policy on EUE.

H2: The NEDC policy mainly promotes energy efficient utilization through two mechanisms: green innovation and forcing industrial structure upgrading.

3 Research design

3.1 Policy background

To spur the energy transformation and optimize the energy mix, the Chinese National Energy Administration announced the establishment of 81 new energy demonstration cities in 2014, as illustrated in Figure 1.

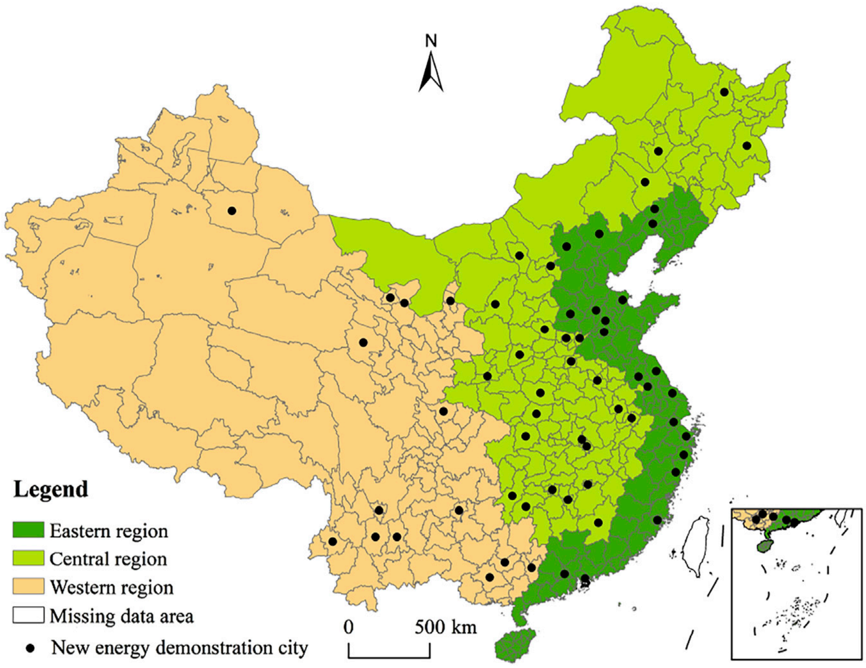

FIGURE 1
Distribution of Chinese new energy demonstration cities.

As depicted in Figure 1, the distribution of demonstration cities across China is widespread, encompassing 26 eastern cities, 28 central cities, and 27 western cities. Considering that China's NEDC policy is a comprehensive new energy policy, the DID method can be used to separate the "policy treatment effect" effectively. In recent years, several scholars have investigated the influence of the NEDC policy on fostering green innovation (Song et al., 2024; Chen et al., 2023; Yang et al., 2021). Liu et al. (2024) thought that NEDC policy would instigate the redirection of production factors, encompassing capital, labor, and technology, towards pilot regions, creating a "siphon effect" that would ultimately contribute to optimizing the energy structure. Gao et al. (2024) believe that implementing the NEDC policy significantly reduces urban CO2 emissions through economies of scale economy and structure upgrading. Most scholars have affirmed the positive effects of this policy, but its impact on EUE still lacks relevant research and is worth further investigation.

3.2 Econometric model

Specifically, the model is set as follows (Equation 1).

$$\mathbf{EUE}_{it} = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 \mathbf{Post} + \boldsymbol{\beta}_2 \mathbf{Treat} + \boldsymbol{\beta}_3 \mathbf{Post} \times \mathbf{Treat} + \boldsymbol{\beta}_j \mathbf{Controls}_{jit} + \mathbf{Citydum} + \mathbf{Yeardum} + \boldsymbol{\varepsilon}_{it} \tag{1}$$

Among them, EUE_{it} refers to the EUE, Post is a time dummy variable whose value equals 1 after 2014, otherwise equals 0; Treat is also a region dummy variable, whose value equals 1 if a city belongs to the treatment group (NEDC), and otherwise equals 0. Controls_j includes a series of control variables. β_3 is the coefficient of Post × Treat, which measures the impact of NEDC policy. Furthermore, this study incorporates Citydum and Yeardum variables to account for both time-invariant city-specific factors and temporal dynamics, thereby enhancing the robustness of the analysis.

3.3 Data resources

This article selects panel data from 273 prefecture-level cities from 2007 to 2020 based on data availability and statistical consistency. In terms of data processing: 1) The data about energy consumption has been sourced from China Energy Statistical Yearbook; 2) Urban macroeconomic data mainly comes from China Urban Statistical Yearbook with missing values filling through the application of linear interpolation methods; 3) The data about green patents comes from Chinese National Intellectual Property Administration. Below is a detailed description of the pertinent variables.

The dependent variable EUE, was calculated using the SBM-DEA method. Drawing upon the research conducted by Chu et al. (2016) and Li et al. (2024), we select labor (number of urban employed population), capital (scale of urban capital stock), and energy (total urban energy consumption) as input factors. Additionally, the total urban GDP is designated as the desired output. Concurrently, the emissions of industrial sulfur dioxide, industrial smoke, and industrial wastewater within the city are identified as undesirable outputs.

Regarding controlling variables, inspired by the research of (He et al., 2024), the following variables have been selected according to

TABLE 1 Descriptive statistics.

Variables	N	Mean	Standard deviations	Min	Max
EUE	3,164	0.325	0.104	0.103	0.831
UR	3,164	0.543	0.154	0.151	1
POP	3,164	5.750	0.924	0.683	7.882
FDI	3,164	0.0180	0.0185	1.77e-06	0.210
PGDP	3,164	10.62	0.620	4.595	13.06
GOV	3,164	0.189	0.191	0.125	3.681

city-level factors that affect energy efficiency. 1) Population Density (POP), which is expressed by total population per unit area, is utilized to capture the influence of agglomeration activities on EUE (Yu et al., 2023); 2) Economic Growth (PGDP), represented by *per capita* GDP, is considered as it fosters the consumption of non-renewable energy sources (Doytch and Narayan, 2016); 3) Urbanization rate (UR), the proportion of urban population to the total population, is used to quantify the influence of urbanization's progression on energy efficiency (Feng et al., 2023); 4) Foreign Investment (FDI) is measured as the ratio of the total import and export volume of the operating unit's location to GDP. FDI discourages the use of unclean energy, potentially promoting energy efficiency (Doytch and Narayan, 2016). 5) Government intervention (Gov), the ratio of general public budget expenditure to GDP. Government intervention will encourage cities to improve EUE (Horbach et al., 2012). The descriptive statistics are presented in Table 1.

4 Empirical results

4.1 Baseline regression

Table 1 shows the descriptive statistics of main variables. Notably, EUE exhibits minimum value 0.103, maximum value 0.831, mean 0.325 and standard deviation 0.104. These statistics underscore substantial variations in EUE during our sample period, thereby offering a solid foundation for investigating the influence of NEDC policy. The results of other variables are similar to those in the relevant literature, for example, Yu et al. (2023) and Kang et al. (2022), which further strengthens the rationality of the study. In addition, the control variables show that the average urbanization rate is 54.3%, and the mean population density is much larger than the variance, indicating that the population distribution is relatively concentrated.

Table 2 displays the regression outcomes about the influence of pilot policies on EUE in the year 2014. Specifically, Column (2) shows the average impacts of the NEDC policy on EUE, with adjustments made for city-specific and time-invariant factors. The regression coefficient associated with the NEDC policy's impact on EUE is 0.019, which is statistically significant. It supports hypothesis H1a, which is consistent with innovation compensation theory. When control variables are incorporated into Column (2) as compared to Column (1), the regression outcomes remain largely unchanged, with a regression coefficient of 0.018 that remains statistically significant. This underscores the significant contribution of NEDC policy in enhancing urban EUE in 2014. The consistency between the results of these two models underscores the robustness of the regression findings. The above results indicate that NEDC policy has significantly improved urban EUE. On the one hand, theoretically speaking, the NEDC policy, in the immediate term, may exert a certain degree of pressure on urban development endeavors. Nevertheless, over a prolonged period, this policy holds the potential to spur enterprises towards technological advancements in production processes, fueled by both compliance imperatives and economic incentives. By enhancing energy efficiency, these enterprises can offset the costs associated with energy consumption. On the other hand, from a strategic viewpoint, the NEDC policy embodies a top-down systematic reform initiated by the central government, which harnesses the combined forces of government guidance and market dominance. Amidst the dual predicaments of environmental degradation and energy transition, the NEDC policy offers a pivotal roadmap for countries seeking to bolster their energy utilization proficiency.

TABLE 2 Baseline regression results.

	(1)	(2)
Treat × Post	0.019***	0.018***
	(3.80)	(3.70)
UR		−0.076***
		(−3.17)
POP		−0.011
		(−1.58)
FDI		−0.213**
		(−2.39)
PGDP		0.032***
		(4.44)
Gov		0.015***
		(5.12)
City	√	√
Year	√	√
N	3,164	3,164
R^2	0.15	0.18

Notes: *, **, *** respectively indicate significant effects at the 10%, 5%, and 1% levels.

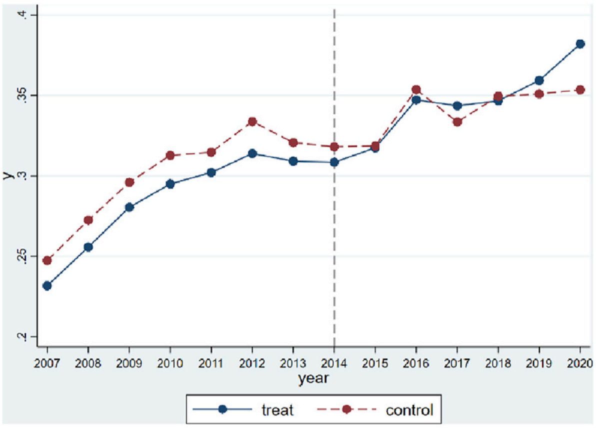

FIGURE 2
Average energy utilization efficiency across various years.

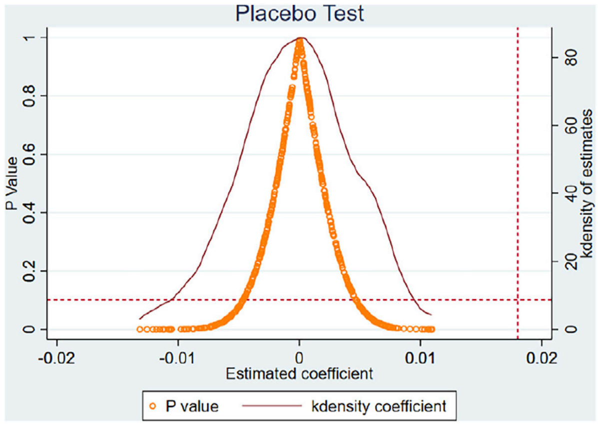

FIGURE 4
Placebo test.

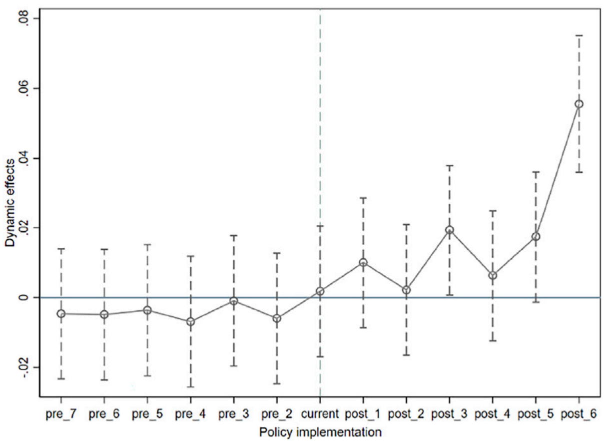

FIGURE 3
Parallel trend test.

4.2 Robustness test

4.2.1 Parallel trend test

This article calculates average energy utilization efficiency in pilot and non-pilot areas, respectively, as shown in Figure 2. Therefore, we can make a simple judgment: the change tendency in pilot and non-pilot areas before 2014 (policy pilot year) was parallel, and energy utilization efficiency in non-pilot areas was higher than in pilot areas. However, after the policy is implemented, the growth rate of energy utilization efficiency in pilot areas is higher than that in non-pilot areas. Since the beginning of 2014, energy utilization efficiency in pilot areas has been close to that in non-pilot areas. This article tentatively speculates that the rapid EUE growth in pilot cities, compared to non-pilot cities, may be attributed to the NEDC policy.

Moreover, the validity of DID estimation hinges on the satisfaction of parallel trend assumption. This premise posits that absent policy intervention, the outcome variables in both groups would exhibit similar trends. Although Figure 2 preliminarily indicates that EUE in pilot and non-pilot cities showed similar trends before the implementation of pilot policies, this article still needs to use more rigorous empirical methods to prove it. In addition, it is crucial to emphasize that the benchmark regression outcomes solely represent the average influence of the pilot policy implementation, failing to capture any potential variations in the impact of these policies across different periods. Therefore, this article adopts the Event Study Approach, as initially introduced by Jacobson et al. (1993) assess the dynamic effects of pilot policies. Subsequently, the following model is formulated to achieve this objective (Equation 2).

$$\mathbf{EUE}_{it} = \beta_0 + \sum_{t=2004}^{2015} \beta_t \mathbf{Treat} \times \gamma_t + \beta_j \mathbf{Controls}_{jit} + \mathbf{Citydum} + \mathbf{Yeardum} + \varepsilon_{it} \tag{2}$$

Figure 3 shows the estimation outcomes of β_t at a 90% confidence interval. This article found that β_t was around 0 from 2007 to 2013 and was insignificant, suggesting an absence of notable differences between the treatment and control groups during this period, thereby fulfilling parallel trend hypothesis. Furthermore, after the policy pilot's implementation, the estimated coefficient β_t gradually increased and became increasingly significant. The reason for the lag impacts may be that the improvement of EUE may rely on industrial restructuring or technological innovation, and both industrial restructuring and technological research and development have the characteristics of large investment and long cycles (Bansal and Hunter, 2003). As a result, there could potentially be a delay or lag in the ultimate manifestation of the policy's effect.

4.2.2 Placebo test

To ensure the robustness of our findings against potential confounding factors such as missing variables or randomness, we draw inspiration from the research of Ferrara et al. (2012) and Li et al. (2016), we construct fake pilot cities and estimate the coefficients using the Equation 1 to assess the reliability of the conclusions. To further strengthen the efficacy of placebo testing, the above process was reiterated 500 times, culminating in the generation of an estimated coefficient distribution graph. Based on this, we can verify whether EUE is significantly affected by other factors besides the NEDC policy. If the estimated coefficients

TABLE 3 Robust tests.

	(1) CCR methods	(2) E/GDP	(3) Eliminate other policies
Treat × Post	0.014**	−0.054**	0.010*
	(2.43)	(−2.29)	(1.72)
Control	√	√	√
City	√	√	√
Year	√	√	√
N	3,164	3,164	2,066
R^2	0.08	0.08	0.14

Notes: *, ** respectively indicate significant effects at the 10%, 5% levels.

under random processing converge toward zero, it signifies that crucial influencing factors have been inadvertently excluded from the model. In essence, this underscores that the effects observed in the benchmark analysis are genuinely attributable to the NEDC policy. As depicted in Figure 4, the distribution plot of estimated coefficients reveals that the coefficients for the false DID items are tightly clustered around 0, and significantly deviate from its true value. This suggests that our model setup is not significantly plagued by omitted variable issues, reinforcing the robustness of our core conclusion.

4.2.3 Replace the explained variable

4.2.3.1 CCR methods

To further validate the robustness of our findings, we employed the conventional CCR method as an additional test. As shown in Table 3, even when utilizing the CCR method to assess EUE, the NEDC policy continues to demonstrate its effectiveness in enhancing this metric.

4.2.3.2 Energy consumption per unit of GDP (E/GDP)

In addition, we utilized the energy intensity metric, specifically E/GDP, as an additional means to gauge EUE. By analyzing the results in Table 3, it becomes evident that NEDC policy effectively reduces E/GDP, ultimately contributing to a heightened level of EUE.

4.2.4 Eliminate contemporaneous policy interference

Various contemporaneous energy policies cannot be ignored for the adjustment of energy structure and the transformation of energy utilization modes. Therefore, to clarify the net effect of NEDC policy on EUE, it is essential to eliminate the interference of contemporaneous energy-saving policies. The energy-saving policies considered in this article mainly include three aspects: first, supportive policies for the development of new energy and policies for optimizing energy consumption structure. Among them, some cities under the jurisdiction of western provinces such as Yunnan, Ningxia, Gansu, Qinghai, and Xinjiang have more advantages in developing solar and wind energy, making them key support objects for the development of new energy. However, coal-consuming provinces such as Shandong, Shanxi, Jiangsu, Hebei, Shaanxi, Inner Mongolia, and Henan have a strong dependence on coal and urgently need to promote the optimization and transformation of energy structure. The second is the energy-saving consumption policy. In 2009, the Chinese Ministry of Finance and the Ministry of Science and Technology jointly announced a notification outlining the initiation of demonstration and promotional pilot initiatives focused on energy-saving and new energy vehicles, setting up three batches of urban pilot projects to accelerate the improvement of EUE through the implementation and promotion of financial subsidy policies for energy-saving and new energy vehicle purchases. The third is the fiscal subsidy program aimed at energy conservation and emission reduction. Chinese National Development and Reform Commission has officially established the first batch of comprehensive pilot projects for energy-saving and emission-reduction fiscal policies followed by the establishment of the second and third rounds of pilot cities in 2013 and 2014, respectively. Based on the above considerations, this article excludes the aforementioned coal-consuming provinces, advantageous regions for the development of new energy in the western region, pilot cities for energy-saving and new energy vehicles, and comprehensive demonstration cities for fiscal policies on energy-saving and emission reduction, to minimize the interference of energy-saving policies during the same period. As demonstrated by the specific estimation outcomes highlighted in column (3) of Table 4, even after excluding samples significantly influenced by concurrent energy-saving policies, the NEDC policy continues to significantly enhance urban EUE at a 1% significance level, reinforcing the conclusion that the NEDC policy effectively improves energy utilization efficiency.

5 Further analysis

5.1 Heterogeneity analysis

5.1.1 Traditional industrial bases and non-traditional industrial bases

The prolonged and inefficient utilization of resources in traditional industrial bases can lead to severe pollution and ecological hazards. Consequently, these cities might encounter the problem of a “resource curse” (Takatsuka et al., 2015). Therefore, we explore the heterogeneity between traditional and non-traditional industrial bases.

TABLE 4 The outcomes of heterogeneity analysis.

	(1) Traditional industrial bases	(2) Non-traditional industrial bases	(3) Eastern region	(4) Central region	(5) Western region	(6) Low economic development	(7) High economic development
Treat × Post	0.011*	0.023***	0.045***	0.003	−0.005	0.001	0.017*
	(1.75)	(2.90)	(4.38)	(0.36)	(−0.57)	(0.20)	(1.82)
Control	√	√	√	√	√	√	√
City	√	√	√	√	√	√	√
Year	√	√	√	√	√	√	√
N	1,057	2,107	1,196	1,149	673	1,582	1,582
R^2	0.13	0.02	0.07	0.07	0.07	0.077	0.137

Notes: *, *** respectively indicate significant effects at the 10%, 1% levels.

In 2013, the Chinese government issued a policy for the construction of traditional industrial bases, "The National Plan for the Adjustment and Transformation of Traditional Industrial Bases (2013–2022)," which has identified 120 traditional industrial bases or districts in the provincial capital city. Several traditional industrial bases serve as crucial energy centers for China, often tasked with supplying essential technical equipment and products integral to people's daily lives. Overall, traditional industrial bases usually have significant characteristics of high energy consumption, which seriously restricts the improvement of EUE in traditional industrial bases. The capacity of the NEDC policy to notably enhance the energy utilization efficiency in traditional industrial bases is intricately linked to the ability of these bases to attain high-quality development. To explore the differences in EUE between traditional industrial bases with non-traditional industrial bases, we distinguished the samples from traditional industrial bases with ones from non-traditional industrial bases and conducted regression analysis separately.

Examining Table 4 (1) - (2), it becomes evident that the NEDC policy has improved EUE in both traditional and non-traditional industrial bases. Notably, the coefficient associated with the interaction term in column (1) stands at 0.011, whereas in column (2), it increases to 0.023, suggesting a more pronounced effect of the NEDC policy on non-traditional industrial bases than traditional ones. It has proven the existence of a resource curse. Or we can give another plausible explanation for this observation that traditional industrial bases inherently possess a relatively high energy intensity, which inherently limits the extent of potential reduction in the short term. The NEDC policy encourages enterprises engaged in the production of key technological equipment to allocate funds towards research and development of energy-saving technologies. Nevertheless, owing to the inherent reliance on existing production technology pathways, the improvement in EUE is relatively small.

5.1.2 Different geographical locations

Considering that the NEDC policy may have heterogeneous impacts for different geographical locations. Based on this, we segment the samples into the eastern, central, and western regions and conduct regression analysis separately. Analyzing columns (3) - (5) of Table 4, we discern that the NEDC policy exhibits heterogeneous effects across distinct geographical regions. Specifically, the coefficient associated with the interaction term in column (3), representing the eastern region, is statistically significant at 0.045, whereas the coefficients in columns (4) and (5), corresponding to the central and western regions respectively, do not demonstrate significant impacts. In conclusion, our findings indicate that the NEDC policy has primarily contributed to enhancing EUE in the developed eastern regions, as opposed to the central and western regions. This conclusion is different from the study of Yang et al. (2022), which found that the impact of the NIPCP policy on energy efficiency in the western region is stronger than that in the eastern and central regions. Our study has proved the existence of a first-mover advantage rather than a late-mover advantage.

5.1.3 Different economic development

Based on this, according to economic development (ED), we divide the samples into the low and high ED samples and conduct regression analysis respectively. From columns (6) - (7) of Table 4, we find that China's NEDC policy also has heterogeneous effects between low ED regions and high ED regions. Specifically, the coefficient preceding the interaction term in column (7), representing high economic development regions, is statistically significant at 0.017, whereas the corresponding coefficient in column (6), for low economic development regions, is not significant. It indicates that the NEDC policy mainly significantly promotes EUE only in high economic development regions. A plausible explanation for this phenomenon lies in the heightened demand for environmental quality among cities with more advanced economies and a higher degree of marketization. This, in turn, motivates them to pursue the development of new energy cities with greater vigor and dedication. Consequently, these cities experience a more significant improvement in EUE.

5.2 Mechanism analysis

The role of industrial restructuring in improving EUE is based on the "structural dividend hypothesis." Specifically, systematic

TABLE 5 The outcomes of mechanism analysis.

	(1)	(2)	(3)	(4)
	Industrial structure upgrading	EUE	Green innovation	EUE
Treat × Post	0.037**	0.018***	0.034**	0.015**
	(2.37)	(3.32)	(2.28)	(2.03)
Industrial structure upgrading		0.023***		
		(3.49)		
Green innovation				0.009***
				(2.83)
Control	√	√	√	√
City	√	√	√	√
Year	√	√	√	√
N	3,164	3,164	3,164	3,164
R^2	0.65	0.13	0.21	0.18

disparities in productivity levels and growth rates across various sectors lead to the reallocation of energy resources. This occurs as energy factors shift from sectors with lower or slower productivity growth to those experiencing higher or faster growth, thereby contributing to an enhancement in the overall energy utilization efficiency across economic sectors. The specific manifestation of this inter-departmental factor flow is the flow of industry to service industry, polluting industry to environmentally friendly industry, etc. The role of industrial structure adjustment in improving EUE (at least in some periods) has been widely confirmed (He et al., 2024). The green and low-carbon transformation of industries can help reduce dependence on traditional fossil fuels, thereby promoting energy structure improvement and energy efficiency enhancement.

The research of Wang and Yi (2021) offers empirical support for the technological advancements stemming from demonstration city construction. The pivotal role of technological advancements in bolstering EUE transcends mere advancements in energy application technologies. It also manifests prominently in diverse aspects, including the refinement of energy management systems, the optimization of energy transportation systems, and the evolution of energy production systems. For example, the improvement of transportation technology helps to reduce losses in the energy transmission process, the optimization of management systems helps to improve the efficiency of energy factor allocation, and the innovation of production processes helps to expand the unit energy output scale in the production process. This means that to gain a more profound comprehension of how the NEDC policy enhances urban EUE, the key is to clarify whether this policy can significantly affect urban industrial structure and technological innovation. Therefore, this article further examines whether these two influential mechanisms are effective.

Table 5 presents the influential mechanism of the NEDC policy about enhancing EUE. Specifically, it investigates the role of industrial structure upgrading through columns (1) and (2). NEDC policy promotes industrial structure upgrading significantly. The NEDC policy has cultivated new energy and green low-carbon industries, and suppressed the development of polluting industries. Enterprises will adjust the combination of production factors and increase investment in environmental protection and clean technologies, thereby promoting the optimization and upgrading of industrial structure (Zhang et al., 2019; Zheng et al., 2021). The results of column (2) reveal that industrial structure upgrading notably fosters urban EUE. The continuous upgrading of industrial structure can reduce the proportion of high polluting and high energy-consuming industries, promote the transformation of industries towards high technology and low pollution, and thus improve urban energy utilization efficiency. Therefore, industrial structure optimization is indeed an important mechanism for improving urban EUE. Columns (3) - (4) examine the mechanism of green innovation, and the results support the innovation compensation hypothesis. The environmental pressure brought by climate risks may force companies to innovate in green technologies (Ren et al., 2024c). After the formulation of NEDC policy, with strong support from government policies, the level of green technology innovation in enterprises has improved, leading to an increase in urban energy utilization efficiency. Overall, this research reveals that the NEDC policy could improve EUE by fostering industrial structure upgrading and green innovation.

6 Conclusion

This research uses the SBM-DEA methodology to calculate EUE, with Chinese cities from 2007 to 2022 as the research sample. A rigorous DID model is performed to thoroughly investigate the impact of the NEDC policy on EUE. The key findings are outlined as follows.

Upon conducting a rigorous battery of robustness tests, including parallel trend test, dynamic time window test, counterfactual test, exclusion of other policy influences, and substitution of explained variables, the NEDC policy significantly improved EUE.

Heterogeneity analysis found that NEDC policy is beneficial for improving urban EUE, whether for traditional industrial bases or non-traditional industrial bases, but the impact on non-traditional industrial bases is greater. The NEDC policy has significantly promoted EUE in the eastern region and high economic development areas, while its impact on EUE in the central and western regions or low economic development areas is not significant.

Mechanism analysis found that the construction of NEDC policy mainly promotes industrial structure adjustment and green innovation to enhance EUE.

Based on these results, the policy implications of this article are as follows.

Firstly, it is worth summarizing the experience of the NEDC policy and subsequently expanding the scope of pilot demonstration cities in a methodical and orderly manner. The NEDC policy plays an essential role in promoting the upgrading of industrial structures and green innovation in pilot cities. Finally, the NEDC policy has improved regional EUE. Therefore, expanding the pilot scope of the NEDC policy can overall enhance China's EUE. Based on the experience of existing NEDC policy, replicable and promotable construction experience can be sorted out according to factors such as the regional location, population size, and resource endowment of pilot cities. The government ought to persist in refining the urban evaluation system by establishing a more scientific and comprehensive evaluation index system. Furthermore, it should methodically expand the number of pilot cities and consistently monitor and assess the quality of their development to ensure continuous improvement.

Secondly, we should design differentiated policy combinations for different cities to enhance EUE. Existing policy design is one size fits all, and lacks targeted and differentiated policy for different regions. Based on the aforementioned empirical findings, the effects of the NEDC policy vary across geographical locations. Specifically, it significantly boosts EUE in the developed eastern regions, whereas its impact is less pronounced in the central and western regions. Consequently, the eastern regions are well-positioned to spearhead the implementation of this policy. They can cultivate innovative talents and enhance their innovation capability in new energy technology, and then increase the radiation and driving ability to the central and western regions. The central regions should encourage enterprises to reduce their dependence on traditional energy while protecting the environment. They can increase the introduction of innovative talents in new energy technology and enhance support for enterprises' research and development. Additionally, they can guide industrial structure upgrading, and thereby improve EUE. The Western regions can rely on their natural resource advantages to enhance the local absorption capacity of the new energy industry. By improving external conditions such as financial support policies, it can attract mature new energy industry chains from the eastern regions. At the same time, by combining the advantageous resources of the western regions, it can cultivate new endogenous energy technology innovation points and improve the EUE in the western regions.

Finally, we can strengthen the supervision of NEDC policy. NEDC policy is a "top-down" implementation path with weak incentives and constraints. To examine the impacts of the NEDC policy, we can construct a scientific and reasonable performance evaluation index system, and conduct long-term, medium-term, and short-term performance evaluations, providing relevant experience for the implementation of NEDC policy in the future. Through phased evaluation and assessment, cities with good construction effects will be affirmed, forming a demonstration role; On the other hand, for cities with unsatisfactory construction results, corresponding governance measures should be introduced, and the subsequent policy adjustment effects should be continuously tracked. A multi-level supervision system should be established to supervise the effectiveness of NEDC policy.

There are still some shortcomings in this study, such as the possibility of spillover effects in the implementation of this policy, which may confuse our empirical conclusions. Anyway, this study is just the beginning, not the end. There are still many topics worth exploring in depth in the future. For example, it is worth further exploring the impact of NEDC policy on the consumption behavior of enterprises and individuals from different individual perspectives in the future; Also, it is interesting to examine the impact of government official turnover on the sustainability of policy implementation; Finally, it still deserves us to explore the spillover effects of the NEDC policy.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SW: Conceptualization, Formal Analysis, Methodology, Project administration, Validation, Writing–original draft. TJ: Formal Analysis, Methodology, Writing–original draft. MH: Methodology, Writing–original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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