Journal of Contemporary Economics and Management

jcem.pol-aca.com

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Can China's national ecological civilization demonstration zones policy enhance urban ecological carrying capacity? Evidence from prefecture-level cities in China

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Citation: Jia, Y., & Li, Y. (2026). Can China's national ecological civilization demonstration zones policy enhance urban ecological carrying capacity? Evidence from prefecture-level cities in China. *Journal of Contemporary Economics and Management. 2*(1), 1-31. https://doi.org/10.65514/z5mgsq93

Abstract: The rapid urbanization and economic growth have brought enormous pressure to urban ecological carrying capacity (UREC). In this context, the Chinese government launched a pilot policy for national ecological civilization demonstration zones (NECZ) in 2013, aimed at promoting ecological civilization and urban sustainable development. Based on panel data from 281 cities in China from 2009 to 2021, this paper constructs a comprehensive evaluation system based on the state-pressure-response model, and uses difference-in-differences model and machine-learning-based causal mediator inference model to quantitatively evaluate the impact of NECZ pilot policy on UREC. Our research has found that pilot policies for China's NECZ can directly and effectively enhance UREC. Mechanism tests reveal that the policy indirectly improves UREC through strengthening at the source, tightening control in the process, and blocking at the end mechanisms. Furthermore, this enhancement effect varies across regions, being more pronounced in western and resource-based cities.

Keywords: Ecological Civilization Construction; Urban Ecological Carrying Capacity; Urban Sustainable Development; Source-Process-End Perspective

1. Introduction

As “nature-economy-society” complexes, cities are the primary carriers of human existence and activities, as well as the main centers for the aggregation of material wealth and commercial transactions. They require substantial consumption of material energy and environmental resources to ensure sustainable development (Li et al., 2019; Ren et al., 2021). In other words, the sustainable development of cities requires urban ecosystems to provide support with maximum capacity as well as carrying capacity (Xu et al., 2010). Unlike traditional natural ecosystems, urban ecosystems are interconnected with and influenced by human economic activities (Costanza, 2020; Zhang et al., 2018). With the prosperous growth of urban economy and the intensification of human activities, urban ecosystems will inevitably face enormous pressure, and their internal metabolic processes will be greatly impacted (Fan & Fang, 2019). This leads to ecological damage, environmental pollution, resource shortages, population surges, and insufficient green space (Starczewski et al., 2023). Therefore, whether the urban ecological carrying capacity (UREC) can withstand such high-intensity impacts, accommodate human activities within its limits, and dynamically maintain its function is a key concern for planners and managers of sustainable cities (Sharifi, 2023; Zhou et al., 2021).

Taking China as an example, with the deepening of the reform and opening-up policy in 1978, China further capitalized on its cost advantages in labor, natural resources, etc. and achieved a magnificent transformation from poverty and backwardness by relying on the driving force of factors and investment (Fan et al., 2021). However, this crude economic development model, overly reliant on resource and energy inputs, has caused irreparable damage to China's urban ecosystems (Chen & Shi, 2022). According to calculations by relevant organizations and departments, the economic losses caused by ecological and environmental issues in China amount to about one-tenth of GDP, which cannot be ignored (Liang et al., 2018). To mitigate the impact of natural disasters and environmental emergencies, the annual investment by the Chinese government in environmental pollution control exhibits a consistent upward trajectory. Concurrently, with the advancement and hastening of industrialization, the pace of China's new urbanization development has also quickened, resulting in an urbanization rate exceeding 46% and a net increase of approximately 742 million urban residents. The pressure of land use has further brought about urban diseases such as the continuous depletion of resources, irreversible degradation of ecological systems, structural shortage of housing supply, and daily traffic congestion (Li et al., 2024a; Meng et al., 2020; Tan, 2023). The 2021 China Environmental Condition Bulletin, released by the Chinese government, indicates that the national ecological environment status index value in 2021 was only 59.77, and the percentage of counties with high-quality ecological conditions compared to the total national land area was just 59.8%. From the characteristics and trends of population and ecological environment, it can be seen that the population size, resource factors, and environmental capacity that support the three basic elements of sustainable development in Chinese cities are basically approaching their peak, and the overall pressure on the UREC of Chinese cities is still very serious. As China's economy is transitioning to high-quality development, the symbiotic relationship between urban sustainable development and UREC not only determines the future development trajectory and overall quality of cities (Shamsipour et al., 2024), but also significantly impacts the enhancement of urban public welfare and residents' well-being (Maes et al., 2019). It is imperative to explore a rational approach for bolstering the UREC and guiding them towards sustainable development. Hence, the study of UREC is of great significance.

Confronted with the global environmental issues, there is widespread international acknowledgment and acclaim of the idea of achieving a harmonious coexistence between humanity and nature to facilitate a balance between the environment and economy (Hansen et al., 2018). In response to the evolving demands of the contemporary era, the Chinese government has consistently adjusted its focal points and development strategies to align with the objectives of sustainable development. In 2012, the establishment of ecological civilization was recognized as a significant component of the comprehensive “Five in One” layout, demonstrating the Chinese government's commitment to tackling environmental concerns (Gu et al., 2020). Furthermore, ecological civilization construction is a pivotal strategy for urban to achieve sustainable development and bolster their UREC, aiming to uncouple environmental degradation from economic progress, while ensuring the harmonization of economic advancement and ecological integrity (Meng et al., 2021). To further explore the Chinese path of ecological civilization construction and achieve sustainable urban development with minimal resource consumption, the Chinese government has adhered to the principles of experimentation and innovation, and released the trial plan for establishing national ecological civilization demonstration zones (NECZ) in December 2013, followed by formally announcements of the official list of cities for China's NECZ in 2014 and 2015. As a practical strategy, the NECZ pilot policy offers an excellent quasi-natural experimental framework for investigating the interplay between ecological civilization and UREC enhancement from a macro policy perspective.

Based on this, this paper uses the NECZ pilot policy as an entry point, combining the perspective of strengthening at the source, tightening control in the process, and blocking at the end, and conducts theoretical deduction and empirical testing using the difference-in-differences model, and machine-learning-based causal mediator inference model, with the aim of answering the following questions: Firstly, can the NECZ pilot policy play an effective role in environmental governance, provide new impetus for the improvement of UREC, and advance urban sustainable development. Secondly, under the framework of the NECZ pilot policy, what paths can be taken to enhance the UREC? Solving the above problems will help reveal the effective path for solving the dilemma of urban sustainable development and the constraints on UREC, providing scientific basis for exploring ecological civilization construction models tailored to China's specific national circumstances.

The marginal contribution of this article may include: firstly, by examining whether the ecological civilization construction policy can effectively enhance the UREC through an analysis of the environmental governance impact of the construction of NECZ. Currently, there is limited literature dedicated to examining the correlation between the NECZ pilot policy and UREC. This study attempts to establish a causal link between the NECZ pilot policy and UREC, offering a fresh research perspective for investigating the policy guidance of ecological civilization construction in advancing urban sustainable development. Secondly, the urban ecosystem is a typical natural-economic-social composite system. It is often difficult to respond to the sustainable development of the composite system using a single indicator and static analysis. Nevertheless, the state-pressure-response model offers an effective solution to this issue. Drawing on this model, we further elucidate the essence of UREC and establishes a comprehensive evaluation system, thereby furnishing empirical insights for investigating the intrinsic correlation between ecological civilization construction and UREC. Thirdly, from the full process perspective of strengthening at the source, tightening control in the process, and blocking at the end, our study thoroughly examines the mechanism of the construction of NECZ on the UREC, further exploring the way out of urban ecological civilization construction dilemmas.

The subsequent sections of this paper are structured as follows: Section 2 comprises the concise review and analysis of the current literature. Section 3 outlines the hypotheses of the research topic. Section 4 offers an elaborate explanation of the models, variables, and data employed in the empirical study. Section 5 presents the results of the empirical study. Finally, Section 6 and 7 deliberate on and draws conclusions from the empirical results.

2. Literature review

The ecological carrying capacity serves as a crucial benchmark for evaluating the sustainability of a nation or area, taking into account the long-term viability of natural resources and ecological surroundings, along with the integrity and coordination between human society and ecosystems. It primarily describes the ability of ecosystems to sustain population activities and economic and social aggregates under conditions of rational resource exploitation and cyclic development of the ecological environment (Arrow et al., 1995; Wang et al., 2022a; Zhang et al., 2023). The notion of carrying capacity originated in the field of engineering mechanics, where it is employed to delineate the maximum load capacity that a building structure can withstand before complete failure. Faced with the continuous growth of population, insufficient reserves of renewable resources, and deteriorating living environment, scholars have gradually introduced and applied the carrying capacity to the research of ecology, environmental science, geography, and even economics. This has led to studies on various types of carrying capacity, including population (Dong et al., 2023), water resources (Zhang & Dong, 2022), water environment (Chen et al., 2022), energy (Zhao et al., 2023), ocean (Yu & Di, 2020), land (Liao et al., 2022), resource and environment (Xu et al., 2023) and tourism (He et al., 2023). In general, from the perspectives of ecological environment and natural resources, research on ecological carrying capacity has roughly gone through various stages. These stages encompass population carrying capacity determined by the maximum biomass of individual populations (Carey, 1993), resource carrying capacity bounded by the relationship between population and resources, environmental carrying capacity bounded by the relationship between population and environment (Tian & Wang, 2013), and ecological carrying capacity defined by sustainable development (Du et al., 2018). With the comprehensive and in-depth of relevant research, ecological carrying capacity has been widely employed for the evaluation of eco-environmental quality, as well as regional ecosystem health (Zhu et al., 2020; Chen et al., 2023). Scholars have employed various methods, such as the grey correlation method (Xu et al., 2010), ecological footprint method (Peng et al., 2019), comprehensive indicator evaluation method (Baohuif & Tuoku, 2020), fuzzy evaluation method (Wu & Hu, 2020), system dynamics model (Wang & Fu, 2023), and BP neural network model (Xiong et al., 2023), establishing a theoretical foundation for the continued expansion of ecological carrying capacity research.

Given the unequivocal acknowledgment of the finite availability of natural resources, it has become challenging to meet the demands of ecosystem resource utilization by focusing solely on a single factor in ecological carrying capacity research. Consequently, research has gradually expanded from single-dimensional factors to multi-dimensional composite ecosystems (Wang et al., 2024a). As a typical nature-economy-society composite system, a city's ecological carrying capacity is a crucial dynamic indicator for measuring and supporting sustainable urban development, which can better adapt to and balance the intricate interrelationships among diverse subsystems within urban ecosystems (Song et al., 2019; Sun et al., 2018). However, UREC is influenced by social construction capacity, economic development capacity, AI management capacity, and cultural factors (Wei et al., 2015; Zhang & Fu, 2023a). Previous studies often focused on single factors, neglecting the holistic nature of urban ecosystems and failing to integrate urban development and ecosystems into a unified theoretical framework, resulting in fragmented and incomplete analyses. It was not until the theory of composite ecosystems was introduced that scholars began to consider UREC as a holistic and systematic concept, leading to preliminary discussions and applications. For instance, Nazer et al. (2023) integrated the ecosystem services into the UREC assessment framework, and devised a new urban decision-making method to ensure sustainable urban ecosystems. Song et al. (2019) designed an evaluation system of UREC based on three dimensions: ecological elasticity pressure, carrying medium support, and carrying object pressure, innovatively using the state-space method for evaluation. Tian and Sun developed an evaluation system of urban comprehensive carrying capacity focusing on the ecological environment, comprehensive transport, and factor market, employing a spatial econometrics model to elucidate the dynamic relationship between the UREC and economic growth. Although their study did not directly mention UREC, the framework is still based on the sustainable development of urban ecosystems. In conclusion, there remains a paucity of comprehensive research on UREC, which needs further exploration.

With the ongoing advancement of the sustainable development strategy, comprehensively improving the UREC requires constant innovation in ideas and concepts, guiding actions to explore new paths. The establishment of ecological civilization signifies a shift and advancement from the conventional industrial civilization (Wei et al., 2011). It is predicated on energy resources and environment carrying capacity, adhering to principles that prioritize the respect, compliance with, and protection of nature, to achieve a state of harmonious symbiotic coexistence between human society and the natural environment (Hansen et al., 2018; Scerri, 2019). Therefore, ecological civilization construction not only prioritizes ecological environmental protection but also emphasizes the integration between socio-economic development and high-level eco-environment protection. This approach is vital for urban areas to enhance their ecological carrying capacity and achieve sustainable development (Deng & Hu, 2024; Marinelli, 2018). Unlike other nations, the Chinese authorities have made significant efforts to promote the strategy of ecological civilization construction, with a focus on improving environmental quality and fostering green, low-carbon growth. China's efforts in this area have attracted significant academic attention. Some scholars have conducted comparative analyses of the development history and lessons learned from China's ecological civilization construction through qualitative research (Xue et al., 2023). Others have constructed evaluation systems for the level of ecological civilization construction using quantitative methods, employing hierarchical analysis, entropy weight TOPSIS, cluster analysis, coupled coordination models, BP neural network models, and spatial econometrics models to explore regional levels, spatial differences, and influencing factors (Hu, 2022; Jiang et al., 2020). Additionally, The establishment of the NECZ, a pivotal environmental policy of the Chinese government, aims to build a scientific resource recycling system, promote resource conservation, enhance natural ecosystem protection, and improve ecological environment quality (Zhang et al., 2024a; Chai et al., 2024). Scholars have found that this policy significantly impacts urban green innovation (Bai et al., 2023; Lee & Nie, 2023), pollution reduction (Yang et al., 2021; Zhang & Fu, 2023b), marine eco-efficiency (Gao et al., 2024), industrial restructuring (Hu et al., 2023), urban carbon efficiency (Li & Han, 2023), and residents' well-being (Li & Xie, 2023). Accordingly, this study contends that the promotion of ecological civilization construction is essential for optimizing the utilization of natural capital and resources to enhance the UREC.

3. Theoretical analysis and research hypothesis

3.1 Direct impact

The NECZ pilot policy aims to explore new paths to sustainable development through comprehensive ecological civilization construction (Gao et al., 2024). These demonstration zones seek to make significant progress in resource utilization, pollution control, and ecological protection by formulating and implementing stringent environmental protection standards and measures (Shao et al., 2024; Shao et al., 2023a), thereby enhancing the UREC. The theory of externalities suggests that industrial production, transportation, and urban living generate significant pollutants, resulting in negative externalities that affect environmental quality and residents' health (Liu et al., 2024a). To address this, national ecological civilization policies internalize the costs of environmental pollution through measures such as environmental taxation, ecological compensation, pollution quotas, emissions trading, strict environmental regulation, and ecological protection and restoration projects (Fersi & Chtourou, 2022). These policies prompt firms and individuals to reduce emissions and adopt cleaner technologies. Specifically, the policy aims to reduce pollution emissions, promote technological innovation and green development, restore and protect ecosystems, and improve environmental governance and social benefits. This is achieved through the imposition of environmental taxes such as carbon tax, the implementation of a pollution quota system and emissions trading, the enhancement of environmental protection standards(Lin et al., 2024a), the strengthening of law enforcement and supervision (Wang, 2024), and the promotion of eco-rehabilitation projects and the construction of green infrastructures (Li et al., 2024b; Timilsina et al., 2024; Xu et al., 2024). These measures address market failures, enhance the UREC, and provide valuable lessons for sustainable development nationwide.

H1: The implementation of the NECZ pilot policy can enhance the UREC.

3.2 Regional differences

The efficacy of the NECZ pilot policy exhibits significant variation owing to a myriad of contributing factors (Sun et al., 2021). One crucial aspect is the economic status of the city, which can exert varying radial influence on the efficacy of policy implementation. Cities with strong economic strength possess ample resources and cutting-edge technology, and are better equipped to promote ecological civilization construction (Yang et al., 2022a). In contrast, developing cities often face financial and technological limitations that hinder their progress. Additionally, the efficiency of policy implementation can differ among regional governments. Certain regions exhibit robust governance and efficient resource allocation, thereby effectively enacting pertinent policies (Meng, 2024). Conversely, others may encounter challenges in realizing the envisaged objectives due to inadequate management or limited resources. What's more, Communities with high environmental awareness are more proactive in supporting green lifestyles (Kuai et al., 2022), while others may be resistant to such changes. On the other hand, geographic location and the natural environment further influence policy implementation. Resource-rich areas are more capable of developing renewable energy, whereas regions with limited natural resources may encounter challenges in adopting similar strategies (Yang et al., 2023). Ultimately, the digital transformation and modernization acceleration of new energy systems, transportation infrastructure and urban buildings play pivotal roles in shaping the viability of the NECZ pilot policy (Hakan Açıkel & Bayır, 2022; X. Zhao et al., 2023). As a result of these diverse factors, the specific outcomes of the NECZ pilot policy implementation can vary widely across different cities. Therefore, a comprehensive comprehension and scrutiny of these characteristics are imperative for formulating and executing efficacious environmental policies.

H2: The implementation of the NECZ pilot policy exhibits diverse characteristics in its efforts to enhance UREC.

3.3 Indirect impact

In addition to the direct impact, the NECZ pilot policy also strengthens from the source, the process of strict control, the end of the blocking of the three indirect pathways to the UREC impact, the conduction mechanism path, and the effect shown in Fig.1.

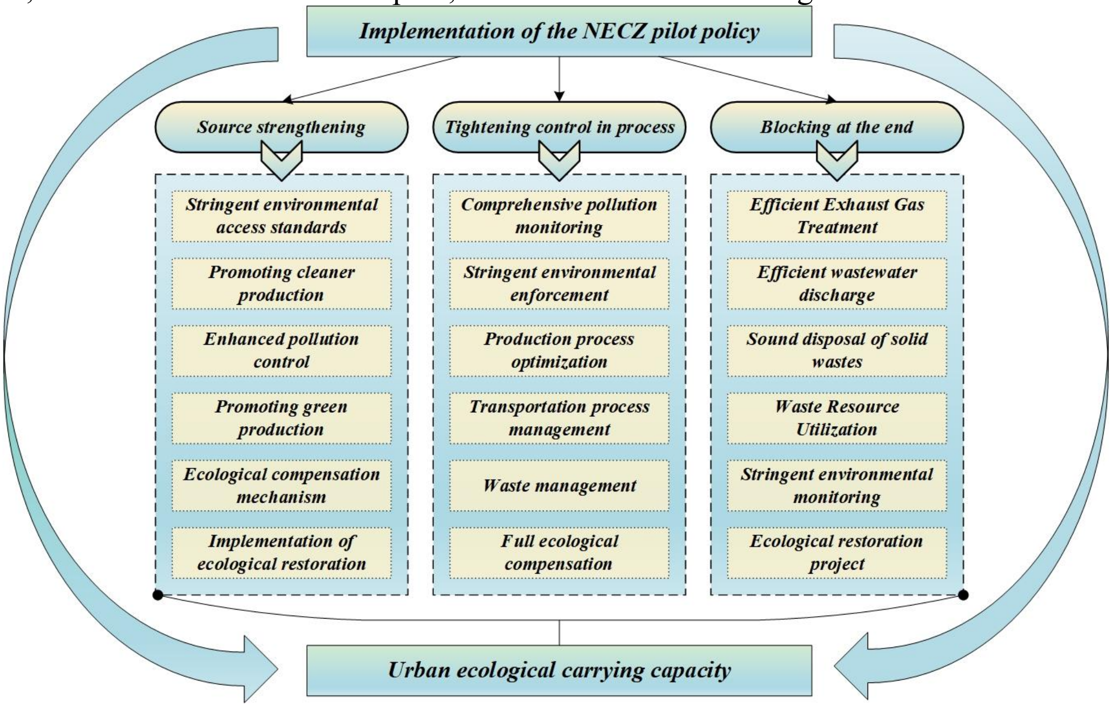

Fig.1. Conceptual model of the mechanism

The “Strengthening at the Source” mechanism aims to control and reduce environmental pollution at its origin and achieve significant ecological improvements. This is accomplished through strict environmental access standards, promotion of cleaner production and technological innovation, stringent pollution control measures, popularization of green production and consumption patterns, the establishment of an ecological compensation mechanism, and implementation of ecological restoration and protection projects (Yang et al., 2022b; Zhang et al., 2024b; Guo et al., 2024). These measures include setting high environmental access standards to ensure new projects comply with environmental protection requirements (Luo et al., 2023); encouraging enterprises to adopt cleaner production technologies and advanced environmental protection equipment through policy incentives and financial support (Tian et al., 2024); strictly enforcing pollution control to ensure that exhaust gas, wastewater, and solid wastes are effectively managed at the source (Choi, 2022); promoting the use of renewable energy, green buildings, and low-carbon transportation to reduce resource consumption and pollution (Wang et al., 2023); establishing an eco-compensation mechanism to compensate enterprises and individuals for economic losses due to environmental protection measures, thereby encouraging greater participation in environmental protection; and advancing eco-restoration projects such as afforestation, wetland restoration, and river management to improve ecological quality at the source. Through these “source-enhancing” measures, the policies of the demonstration zones can effectively reduce environmental pollution, enhance the UREC, promote sustainable development, and provide valuable experience and demonstration effects for other regions.

H3a: The implementation of the NECZ pilot policy can enhance the UREC through the mechanism of strengthening at the source.

The “Tightening Control in the Process” mechanism aims to achieve sustained ecological improvement through strict monitoring and management of pollution discharge at every stage of production, transportation, use, and disposal. Within the demonstration zone, the government can establish a comprehensive pollution monitoring system utilizing advanced technologies such as the Internet of Things (IoT) and big data analytics to monitor all aspects of industrial production, transportation, and domestic waste disposal in real-time. This allows for the timely identification and management of pollution sources, preventing the spread and accumulation of environmental contaminants (Bi et al., 2024). The government enforces strict environmental regulations through high-frequency inspections and unannounced spot checks, creating a high-pressure environment that compels enterprises to enhance their environmental awareness and management (Li & Ma, 2024). Enterprises are encouraged to adopt cleaner production technologies and optimize processes to reduce the generation of exhaust gas, wastewater, and solid waste. This includes improving production equipment, optimizing processes, and using environmentally friendly raw materials (H. Xu et al., 2023). Environmental management of the transportation process is strengthened by promoting new energy vehicles, optimizing transportation routes, and reducing vehicle idling and waiting times, thereby decreasing fuel consumption and emissions. Waste treatment is improved through scientific and standardized methods to ensure that domestic and industrial waste does not cause secondary pollution during treatment. The promotion of garbage classification, the establishment of a comprehensive recycling system, and the development of efficient waste treatment facilities increase the utilization rate of resource recycling, thereby reducing the environmental pressure from landfills and incineration (Zhang et al., 2024c). A whole-process eco-compensation mechanism is implemented to compensate for economic losses resulting from environmental protection measures in production, transportation, use, and disposal, encouraging enterprises and individuals to adopt eco-friendly practices at all stages (Wu et al., 2024). Through the "Tightening Control in the Process" mechanism, the NECZ pilot policy ensures that pollution emissions are strictly monitored and managed throughout the entire lifecycle of production, transportation, use, and disposal, minimizing environmental impact at all stages. Comprehensive pollution monitoring, strict environmental law enforcement, production process optimization, transportation management, waste treatment, and eco-compensation have effectively reduced environmental pollution and enhanced the UREC.

H3b: The implementation of the NECZ pilot policy can enhance the UREC through the mechanism of tightening control in the process.

The “Blocking at the End” mechanism aims to achieve significant ecological improvements by treating and eliminating pollutants generated during production and daily activities to ensure they do not further impact the environment. The government in the demonstration zone mandates that enterprises install efficient exhaust gas treatment equipment, such as dust collectors, desulfurization devices, and denitrification equipment, to remove hazardous gases and particulate matter, thereby improving air quality (Jiang et al., 2021). Enterprises and wastewater treatment plants are required to adopt biological treatment, physicochemical treatment, and advanced oxidation technologies to ensure wastewater meets environmental standards before discharge, preventing water contamination (Wang et al., 2024b). Enterprises are encouraged to adopt technologies for garbage incineration, resource utilization, and safe landfills to ensure the harmless treatment of solid wastes, thereby reducing soil and groundwater pollution (Chen et al., 2024). The policy promotes resource utilization of wastes through recycling, reuse, and recovery to reduce resource waste and environmental pollution. A strict environmental monitoring and enforcement system is established to ensure compliance with environmental regulations through real-time monitoring and frequent inspections, preventing the omission of end-of-pipe pollution treatment measures (Chen et al., 2023). Ecological restoration projects, such as tree planting, wetland restoration, and soil remediation, are implemented to repair damaged ecosystems and enhance the environment's self-healing capacity (Yu et al., 2022). Through these measures, the NECZ pilot policy effectively reduces environmental pollution, enhances the UREC, ensures the final treatment and elimination of pollutants, and promotes sustainable urban development, providing valuable experience and demonstrative effects for other regions.

H3c: The implementation of the NECZ pilot policy can enhance the UREC through the mechanism of blocking at the end.

4. Methodologies

4.1 Econometric model setting

In December 2013, China's authoritative institutions officially issued the Programme for the NECZ pilot policy. This report proposed selecting typical representative areas to construct NECZ, aiming to establish advanced models for nationwide promotion. Consequently, this paper adopts the difference-in-differences (DID) model to assess the policy effects of these pilot zones, and the following model can be constructed by combining the main variables explored in this paper:

$$UREC_{it} = \alpha_1 + \beta_1 NECZ_{it} + \gamma_1 X_{it} + \mu_i + \omega_t + \varepsilon_{it} \tag{1}$$

In model (1), UREC_{it} represents the UREC of prefectural city i in year t; α_1 represents the intercept term; $NECZ_{it}$ is employed to ascertain whether city i has been designated as a pilot city in year t, serving as the virtual variable in this paper with assignable values of 0 or 1; β_1 is the coefficient of primary interest in this paper, representing the net effect of NECZ pilot policy on UREC; X_{it} denotes a set of influential control variables on UREC, while γ_1 signifies the corresponding estimated coefficients. Meanwhile, μ_i corresponds to the fixed effect specific to each city, and ω_t refers to the fixed effect specific to each year. Lastly, ε_{it} stands for the random disturbance term. In addition, for the DiD model, it is indispensable to carry out the parallel trend test on it, with the specific formula for this test being as follows:

$$UREC_{it} = \alpha_2 + \sum\nolimits_{m=-4}^{0} \eta_m NECZ_{it}^{m} + \sum\nolimits_{n=0}^{6} \delta_n NECZ_{it}^{n} + \gamma_2 X_{it} + \mu_i + \omega_t + \varepsilon_{it} \tag{2}$$

In model (2), $NECZ_{it}^{m}$ and $NECZ_{it}^{n}$ represent the urban virtual variables of NECZ; m and n represent the periods m years prior to and n years following the implementation of the policy, respectively. Other variables are maintained in accordance with the model (1). In this paper, we also refer to the practice of Zhu and Jiang (2024) by using one year before the policy establishment as the base period.

4.2 Variables selection

4.2.1Explained Variables: UREC

To measure UREC, a comprehensive evaluation system is constructed based on the "Pressure-State-Response" model. This evaluation system incorporates three first-level indicators: pressure, state, and response (Table 1). The entropy weighting method is employed to assign weights to these indicators, allowing for the calculation of the comprehensive UREC level in China. Additionally, to ensure consistency in the statistical analysis, all indicators are standardized.

Table 1 . The UREC measurement system

Primary indicator	Secondary indicator	Tertiary indicator	Unit	Attribute
Pressure	Economic pressure	GDP per capita	¥	+
		Economic density	billions ¥/km^2	−
	Resource pressure	Population density	person/km^2	−
		Natural growth rate	%	−
	Ecological pressure	Industrial wastewater discharge	t	−
		Industrial waste gas emissions	m^3	−
State	Production status	Industrial waste gas emissions	m^3/10,000 ¥	−
		Industrial dust emissions	t	−
		Industrial wastewater	t/10,000 ¥	−
		Green space per capita	m^2	+
	Environmental status	Water resources per capita	m^3/person	+
		Built-up area	km2	−
		Annual average concentration of respirable fine particulate matter	ug/m^3	−
Response	Government response	Science Expenditures	10,000 ¥	+
		Urban landscaping green space area	hm^2	+
		Expenditures within the general budget of local finance	10,000 ¥	+
	Social response	Centralized treatment rate of sewage	%	+

	treatment plants		
	Comprehensive treatment rate of domestic garbage	%	+
	Completed investment in industrial pollution control	10,000￥	+

4.2.2Explanatory variables: NECZ pilot policy

The list of pilot cities recognized in this paper is based on the official roster released by the Chinese government The central government designated two batches of NECZ pilot cities: the initial round in 2014 and the subsequent round in 2015. As of 2021, a total of 116 cities had been designated as NECZ pilot cities, and this paper employs these 116 pilot cities as the experimental group. Meanwhile, in accordance with the principle of data availability, the control group comprised 165 other cities that were not designated as NECZ pilot cities. The geographic distribution of these pilot cities is detailed in Fig. 2, providing a visual representation of their specific locations.

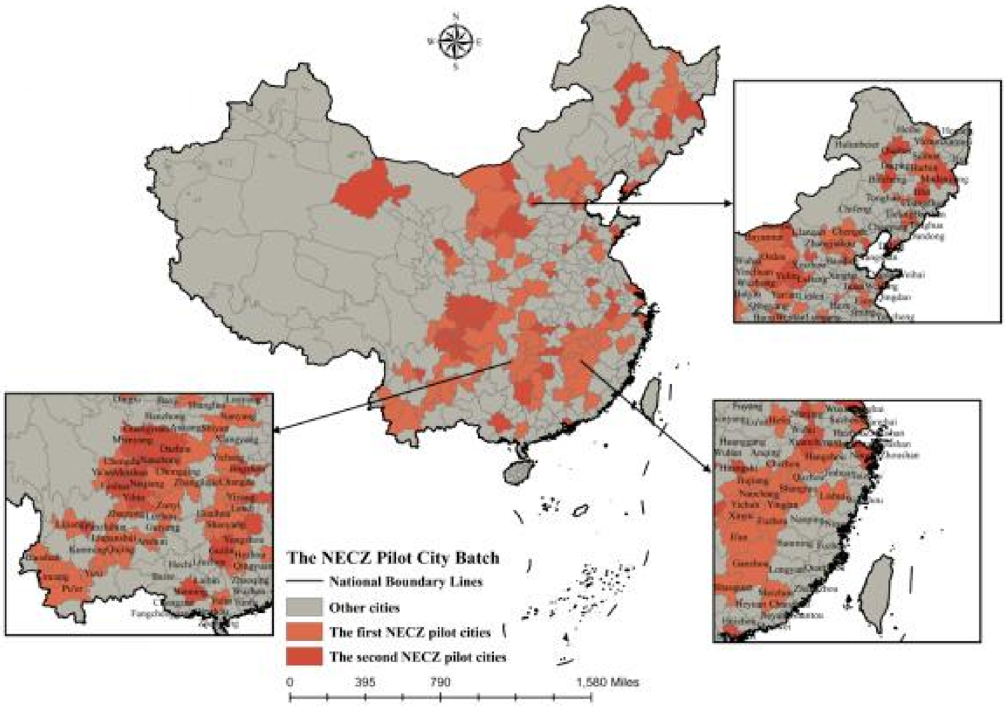

Fig. 2. The geographic distribution of pilot cities

4.2.3Control variables

Referring to previous research by Wang et al. (2021), Su et al. (2024), and Qiao et al. (2024) and mindful of addressing endogeneity concerns, the frequency of environment-related phrases in government work reports serves as an indicator of environmental regulation (ENR); the per capita disposable income is chosen as a proxy for living standard (LIVE); the ratio of import and export to local GDP serves as a proxy for external openness level (OPEN). Furthermore, the proportion of gross industrial output in GDP is selected as an indicator reflecting the level of the manufacturing sector (IND), while the quantity of internet users can serve as an indicator for the degree of informatization (DIN).

4.2.4Mechanism variables

In this study, to deeply explore the influence path of the NECZ pilot policy on UREC, three mechanism variables are specially set up, namely, strengthening at the source, tightening control in the process, and blocking at the end. The selection of these three mechanism variables aims to reveal the specific mechanisms of policy implementation on environmental improvement through different perspectives and levels.

First, Strengthening at the Source (Stc): The Stc mechanism focuses on reducing environmental pollution and resource consumption by optimizing the industrial structure to enhance the UREC (Lai et al., 2021). This study uses the industrial structure advancement index as a proxy for this mechanism. The industrial structure advancement index measures the degree of industry upgrading and transformation, reflecting the shift of economic activities to high-technology and high-value-added industries. This shift reduces the proportion of high-pollution and high-energy-consuming industries, promotes clean production and a green economy, and alleviates environmental pressure at the source.

Second, Tightening Control in the Process (Tcp): The Tcp mechanism focuses on reducing pollutant emissions and environmental burdens through technological innovation and stringent management during production and operation. This study selects green technological innovation as a proxy for Tcp. Green technological innovation encompasses advancements in production processes, equipment, and materials aimed at reducing exhaust, wastewater, and solid waste generation (Feng et al., 2021). These innovations not only increase production efficiency and reduce resource consumption but also significantly enhance the environmental performance of the production process (Khattak et al., 2024). By promoting and applying green technology, enterprises can achieve pollution control and resource savings during production, thereby enhancing the UREC.

Third, Blocking at the End (Bke): The Bke mechanism focuses on the effective treatment and utilization of pollutants already generated, preventing them from further impacting the environment. The comprehensive utilization rate of industrial solid waste is chosen as a proxy for the Bke. This indicator reflects the treatment and reuse of industrial solid waste at the end of the production process. By enhancing the comprehensive utilization rate of solid waste, it leads to a reduction in final waste disposal, thereby minimizing the potential for soil and water contamination (Li et al., 2024c). Furthermore, the utilization of solid waste resources not only conserves valuable resources but also yields a symbiotic outcome in terms of both economic and environmental benefits. The Bke mechanism further reduces environmental pollution and enhances the UREC through effective waste management and treatment.

4.3 Data collection source

This study utilizes panel data from 281 cities in China, covering the period from 2009 to 2021. The Hong Kong, Macao, Taiwan, and Tibet are excluded due to constraints on data availability.

The variable data were obtained from official statistical yearbooks published by the Chinese government. Table 2 provides descriptive statistics for each variable.

Table 2 . Descriptive statistics of variables

Variables	Obs	Mean	Std	Min	Max
UREC	3,653	0.2215	0.0094	0.1629	0.2751
Pressure	3,653	0.2300	0.0125	0.1544	0.2675
State	3,653	0.5926	0.0350	0.4795	0.7999
Response	3,653	0.1410	0.0232	0.0518	0.2963
NECZ	3,653	0.2406	0.4275	0.0000	1.0000
ENR	3,653	229.0522	14.5162	183.1200	283.5700
DIN	3,653	2.4304	1.1792	0.5879	21.3015
OPEN	3,653	0.0424	0.0495	0.0000	1.0000
LIVE	3,653	0.3779	0.1083	0.0000	1.0126
IND	3,653	0.0338	0.0172	0.0034	0.1585
Stc	3,653	0.0204	0.0301	0.0000	1.0000
Tcp	3,653	0.0201	0.0666	0.0000	1.0000
Bke	3,653	0.0111	0.0388	0.0000	1.0000

5. Results

5.1Benchmark regression results

According to the model settings, this study empirically investigated the influence of the NECZ pilot policy on UREC. The results are presented in Table 3, with column (1) displaying the regression results of the NECZ pilot policy on UREC, while columns (2)-(4) present the results on various criterion layers. The positive and statistically significant regression coefficient of the NECZ pilot policy on UREC at a 1% significance level suggests that it can enhance UREC by approximately 0.0009. Similarly, the positive and statistically significant regression coefficients of the NECZ pilot policy on pressure and state at a 1% significance level indicate that it can help mitigate pressure on UREC and improve the city's environmental status. However, the regression result of the NECZ pilot policy on response is not statistically significant.

Table 3. Benchmark regression test

	(1) UREC	(2) Criterion Layers-P	(3) Criterion Layers-S	(4) Criterion Layers-R
NECZ	0.0009*** (0.0002)	0.0014*** (0.0003)	0.0033*** (0.0010)	0.0010 (0.0008)
LIVE	0.0001** (0.0001)	0.0001 (0.0001)	0.0003*** (0.0001)	0.0002*** (0.0001)
DIN	-0.0002** (0.0001)	-0.0007*** (0.0003)	-0.0013* (0.0007)	-0.0004 (0.0005)
OPEN	0.0001 (0.0043)	0.0040 (0.0079)	0.0101 (0.0195)	0.0059 (0.0161)
IND	-0.0025** (0.0012)	0.0009 (0.0018)	-0.0025 (0.0046)	-0.0009 (0.0037)
ENR	-0.0189 (0.0137)	0.0683*** (0.0191)	0.1188** (0.0555)	0.0695 (0.0493)
_cons	0.2109*** (0.0058)	0.2227*** (0.0062)	0.5210*** (0.0183)	0.0874*** 0.0140
Year &	√	√	√	√

City-FE				
N	3,653	3,653	3,653	3,653
R2	0.8672	0.8300	0.8374	0.7415

5.2 Parallel trend test

While the implementation of the NECZ pilot policy may be considered relatively randomized, it is imperative to conduct a parallel trend test to ensure the presence of a consistent trend in the research sample, and the results of this test are presented in Fig. 3. The coefficients associated with the NECZ pilot policy were statistically insignificant before its introduction; however, they exhibited significant positive effects in the third year following its implementation, which indicates that the NECZ pilot policy successfully passes the parallel trend test and, similar to numerous lagged policies discussed in existing literature, there exists a discernible time lag before realizing its positive impact on UREC.

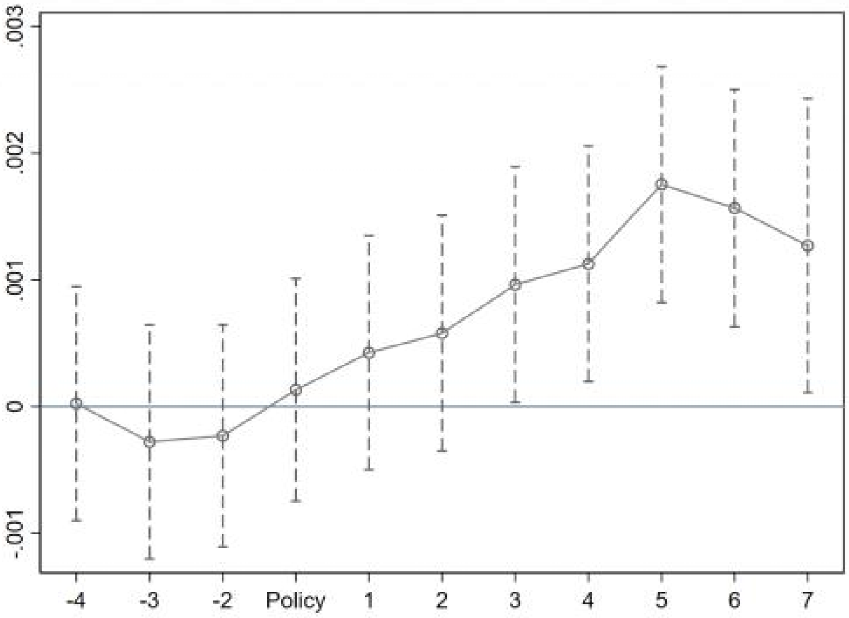

Fig. 3. Parallel trend test

5.3 Placebo test

The study aimed to confirm that the NECZ pilot policy's effect on UREC was due to the policy itself and not other factors. To achieve this, several placebo tests were conducted, including temporal, spatial, and mixed tests (Fig. 4). The temporal placebo test involved advancing the policy implementation date by three years to ensure that changes in UREC were not due to pre-policy factors. The individual placebo test randomly assigned samples to experimental and control groups to verify that significant unknown variables did not affect UREC. The mixed placebo test involved randomizing both time and individual assignments. The results showed that the temporal placebo test produced a non-significant and near-zero coefficient for the NECZ policy advanced by three years. Moreover, the distribution of coefficients closely resembled a normal distribution with its center at zero. This indicated no significant effects in the random grouping. Therefore, the benchmark regression conclusion is more credible, affirming that the NECZ policy's effect on UREC was genuine and not due to unidentified factors.

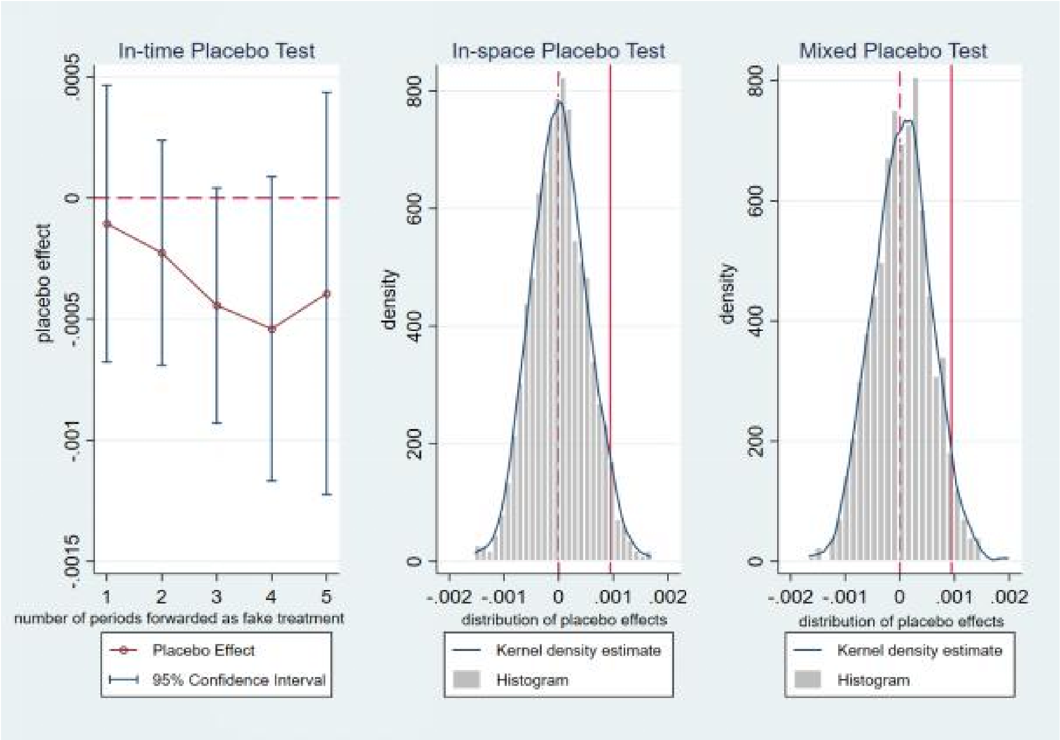

Fig. 4. Placebo test

5.4 Robustness tests and endogeneity treatment

The government's implementation of the NECZ pilot policy may occur in the latter half or at the end of the year, resulting in delayed effects. The parallel trend test further substantiates the presence of the temporal lag effect. Therefore, in the benchmark regression model, as depicted in column (1) of Table 4, this study incorporates a one-period lagged NECZ pilot policy variable. The lagged NECZ pilot policy exhibits a significantly positive impact on UREC, thereby affirming the robustness of the findings in this paper.

Other policies, particularly those related to the environment, could influence the estimation results if introduced during the study period. To exclude the impact of other similar policies, this study incorporates low-carbon pilot policies into the benchmark regression. The findings in column (2) of Table 4 indicate that the regression coefficient of the NECZ pilot policy on UREC remains statistically significant, confirming the robustness of the benchmark regression results after excluding other policy effects.

To further address the non-randomness of sample selection and reduce systematic bias between cities with and without NECZ pilot policies, this paper utilizes the propensity score matching-double-difference (PSM-DID) method to verify. After conducting annual nearest neighbor matching to align the experimental and control groups, and excluding samples within the same interval as the experimental group, 3,099 samples remained for regression analysis. The estimation results, shown in column (3) of Table 4, demonstrate that the NECZ pilot policy continues to have a significant positive effect on UREC, confirming the robustness of the findings.

Table 4 . Robustness test and endogeneity treatment

	(1) UREC	(2) UREC	(3) UREC
L. NECZ	0.0011*** (0.0002)		
NECZ		0.0009***	0.0008***

		(0.0002)	(0.0003)
_cons	0.2120*** (0.0060)	0.2109*** (0.0058)	0.2138*** (0.0067)
CV	√	√	√
Year & City-FE	√	√	√
N	3372	3653	3099
R2	0.8794	0.8672	0.8639

5.5 Heterogeneity analysis

(1) Geographical location Heterogeneity: Based on geographical characteristics, the research sample of 281 cities was categorized into three regions (East, Central, and West). The value of east is set to 1 if the sample belongs to the eastern region, and 0 otherwise. The same method applies to the remaining variables. Regional dummy variables are then multiplied by the policy variables to construct the triple difference and analyze regional heterogeneity. Based on the estimated results in columns (1) - (3) of Table 5, it is evident that the NECZ pilot policy exerted a largest positive influence on UREC in the Western region (0.0017), a comparatively weaker negative effect in the Eastern region (-0.0013), and no statistically significant correlation in the Central region.

(2) Urban potential endowment heterogeneity: Referring to the official document released by the Chinese authoritative institutions, we categorized the research sample of 281 cities into resource-based and non-resource-based categories, employing methodologies similar to those described in the section of geographical location heterogeneity. Based on the estimated results in columns (4)-(5) of Table 5, The coefficients of the NECZ pilot policy exhibit statistically significant positive values at the 1% level, with cities endowed with resources demonstrating larger coefficients compared to those without.

Table 5. Heterogeneity test

	(1)	(2)	(3)	(4)	(5)
NECZ	0.0009*** (0.0002)	0.0009*** (0.0002)	0.0009*** (0.0002)	0.0008*** (0.0001)	0.0010*** (0.0002)
NECZ*East	-0.0013*** (0.0004)				
NECZ*Central		0.0000 (0.0003)			
NECZ*West			0.0017*** (0.0007)		
_cons	0.2118*** (0.0058)	0.2110*** (0.0058)	0.2096*** (0.0058)	0.2039*** (0.0091)	0.2209*** (0.0062)
CV	√	√	√	√	√
Year & City-FE	√	√	√	√	√
N	3653	3653	3653	2234	1419
R2	0.8677	0.8672	0.8676	0.8763	0.8415

5.6 Mechanisms test

The aforementioned study illustrates the beneficial impact of the NECZ pilot policy on UREC, but it is still crucial to examine the pathways through which UREC is enhanced. As previously mentioned, this paper explores how the NECZ pilot policy affects UREC from the perspectives of source strengthening, process control, and end blocking, with reference to the machine-learning-based causal mediator inference model of Farbmacher et al. (2022). The model is configured as follows:

$$ATE = E\left[Y\left(1,F\left(1\right)\right)-Y\left(0,F\left(0\right)\right)\right] \tag{3}$$

$$\phi\left(1\right) = E\left[Y\left(1,F\left(1\right)\right)-Y\left(0,F\left(1\right)\right)\right] \tag{4}$$

$$\phi\left(0\right) = E\left[Y\left(1,F\left(0\right)\right)-Y\left(0,F\left(0\right)\right)\right] \tag{5}$$

$$\varphi\left(1\right) = E\left[Y\left(1,F\left(1\right)\right)-Y\left(1,F\left(0\right)\right)\right] \tag{6}$$

$$\varphi\left(0\right) = E\left[Y\left(0,F\left(1\right)\right)-Y\left(0,F\left(0\right)\right)\right] \tag{7}$$

Meanwhile, The relevant model specifications align with those presented in Farbmacher et al. (2022). Model (3) represents the average treatment effect (ATE), encompassing both direct and indirect effects; while Model 4) to (7) delineate the direct effects of the treatment and control groups, as well as the indirect effects of the treatment and control groups.

In accordance with the findings presented in Table 6, All average treatment effect of the regression were statistically significant, and there was no substantial change in the coefficients' signs, affirming the robustness of the results in this paper. Meanwhile, further examining the regression results for different paths, with a particular focus on the indirect effects within the treatment and control groups. Within the Stc group, the indirect effects for both the treatment and control groups are positive and significant, indicating that the NECZ pilot policy improves UREC through strengthening at the source. Within the Tcp group and the Bke group, the treatment group exhibits positive and statistically significant indirect effects, whereas the effects on the control group do not reach statistical significance. These findings suggest that the NECZ pilot policy enhances UREC in pilot cities through tightening control in the process and blocking at the end.

Table 6. Mechanism Tests

	Average treatment effect	Dir. treat effect	Dir. control effect	Indir. treat effect	Indir. control effect
Stc	0.0041***	0.0033***	0.0032***	0.0008***	0.0008***
	(0.0004)	(0.0003)	(0.0003)	(0.0003)	(0.0002)
Tcp	0.0040***	0.0037***	0.0037***	0.0003**	0.0003
	(0.0004)	(0.0003)	(0.0003)	(0.0001)	(0.0003)
Bke	0.0041***	0.0038***	0.0038***	0.0003**	0.0003
	(0.0004)	(0.0003)	(0.0003)	(0.0001)	(0.0002)

6. Discussion

Based on the empirical analysis in Chapter 5, several key findings emerge. First, the NECZ pilot policy significantly enhances NECC. This result aligns with the findings of Gao et al. (2024), who measured local marine eco-efficiency using panel data from 11 Chinese coastal provinces from 2006-2019 and demonstrated through empirical tests that the NECZ pilot policy positively affects marine eco-efficiency, supporting our conclusions. Although studies specifically involving UREC are fewer, research on other environmental pilot policies shows significant effects on various factors such as environmental performance (Li et al., 2024d), low-carbon technologies (Wang & Chu, 2024), energy poverty (Song et al., 2024), and corporate sustainable development (Yu et al., 2024). These studies consistently find that pilot policies in the environmental category yield significant environmental benefits.

Second, Strengthening at the source is prominent in the NECZ pilot policy for NECC, aligning with discussions on industrial structure upgrading (Pan et al., 2023; Jiang et al., 2024; Tian & Zhang, 2024). Notably, industrial structure upgrading can be a double-edged sword (Chang et al., 2023; Yu & Li, 2023). Many manufacturing firms pursue benefits through various industrial transformations, such as digital (Meng et al., 2023) and service-oriented transformations (Dou et al., 2024). While such upgrades can be lucrative long-term (Zou, 2024), they may not be rewarding in the short term and can even lead to transformation dilemmas (Wang et al., 2022b; Zhuo & Chen, 2023). This study focuses on industrial transformation and upgrading within the NECZ pilot policy to promote UREC. The results indicate that controlling the source of production and manufacturing is favorable to UREC. However, this conclusion may change if the study scope includes economic or green economic benefits (Lin et al., 2024b). Additionally, Tightening control in the process and Blocking at the end are crucial in the NECZ pilot policy for promoting NECC. This suggests that enhancing firms' green innovation capabilities and strictly controlling pollution emissions significantly boost NECC (Chang & Wang, 2024; Miao et al., 2024). Although increasing R&D investment and improving green technological innovation is essential for sustainable development (Fang, 2023; Song et al., 2023), positive externalities of green technological innovations (Xie et al., 2024) mean many manufacturing firms will neglect production technology investment and ecological responsibility without policy tools.

Third, the NECZ pilot policy has been most effective for UREC in the western region. In contrast, UREC in the eastern and central regions did not benefit as significantly from the policy. This differential finding is not unique, as Lu et al. (2024) found that the carbon emissions trading pilot policy is more effective in curbing urban pollution in less developed regions of China. However, Zhao et al. (2024) showed that the FinTech pilot policy does not produce the expected benefits of corporate environmental disclosure in less developed regions. Given the similarity of this study's regional delineation to other research, understanding China's geographic development characteristics is crucial to exploring such divergent results (Zeng et al., 2024). Generally, developed regions, unlike less developed regions, already have economic foundations, and implementing the NECZ pilot policy in these areas may result in diminishing marginal benefits (Menegat, 2024). Additionally, less developed regions have not yet faced significant environmental pressures and political performance assessment indicators (Huang et al., 2025; Wang et al., 2024c), making the integrative effect of the NECZ pilot policy on local resources challenging to realize. Furthermore, empirical results by resource type show that the NECZ pilot policy more evidently promotes UREC in resource-based cities. This phenomenon may be attributed to the relatively homogeneous industrial structuresand backward technology levels in resource-based cities (Li et al., 2024e; Liu et al., 2024b). Considering marginal benefits, resource-based cities are better able to achieve technological upgrading and industrial restructuring from the NECZ pilot policy, which is more conducive to improving UREC.

Based on the above findings and in-depth discussion, this paper presents the subsequent policy recommendations: First, it is recommended to expand and deepen the coverage and implementation of the NECZ pilot policy, especially in the developed eastern and central regions that have not yet benefited. Enhancing policy support and resource allocation in these regions will improve green technology innovation capacity and ecological responsibility awareness, ensuring a balanced distribution of policy effects. Second, the government should strengthen support and guidance for industrial structure upgrading. This includes promoting digital and service-oriented transformations by providing policy preferences and financial support. Additionally, establishing special funds and technical support platforms will help enterprises overcome challenges during transformation, ensuring the smooth advancement of industrial upgrading. Third, when formulating and implementing the NECZ pilot policy, regional differentiation should be optimized according to local conditions. In the western region, continue to enhance policy support and resource integration to improve technological upgrading and industrial restructuring. For the developed eastern and central regions, explore new policy tools and implementation paths to address diminishing marginal benefits and environmental pressures.

It is important to note that implementing policies often encounters resistance and challenges. Identifying these potential challenges is essential. First, expanding the pilot policy requires substantial financial and resource support. However, under economic pressure, local governments and enterprises may face financial difficulties in providing sufficient support (Shirazi, 2023). Additionally, regional differences in economic development, industrial structure, and resource conditions necessitate a high degree of coordination and integration for unified policy implementation and monitoring (Bissiri et al., 2024), adding complexity to the process. Second, industrial structural upgrading often takes a long time to yield results. Firms and local governments may prioritize short-term economic benefits (Cai et al., 2023), leading to insufficient incentives for policy implementation. Moreover, during industrial transformation, enterprises may face market and technological risks (Zhang & Li, 2024), causing operational difficulties or even closures. Third, optimizing regional differentiation policies requires balancing regional interests to avoid conflicts and policy resistance due to unfair resource distribution. Specific regions, such as resource-based cities, may face severe environmental and social problems, such as resource depletion, pollution, and social instability(Shao et al., 2023b). These issues must be addressed concurrently during policy implementation to ensure the policy's effectiveness.

7. Conclusion

We acknowledge the limitations of this paper and aim to provide insights for future research based on these limitations. First, regional differences and sample representativeness. Although this article considers the differences in policy effects between regions, it does not fully explore the specific reasons behind these differences using empirical analysis. Second, the selection of control variables. While this article draws on the research of many scholars to select appropriate control variables, it is still challenging to ensure that no relevant control variables are omitted. Third, future impact and sustainability prediction. Although this paper empirically examines the direct impact, indirect impact, and regional differences of the NECZ pilot policy on UREC, it does not address the future effects of the NECZ pilot policy and its sustainability. These shortcomings suggest new directions for future research. First, a more in-depth analysis of regional differences. Future research can explore the differences in NECZ pilot policy implementation across regions in greater depth, including the strength of policy implementation and the impact of local fundamental conditions. Second, the inclusion of control variables. Future research could analyze the connotations of NECZ pilot policy and UREC more extensively to ensure the selection of reasonable control variables. Third, future effects and sustainability assessment. Future research could focus on the policy's future effects and its sustainable strength, particularly concerning ecological, economic, and social sustainability.

AUTHOR CONTRIBUTIONS

Yunxi Jia: Writing-original draft, Writing – review & editing, Conceptualization, Methodology, Data curation, Software, Visualization, Validation.

Yi Li: Resources, Project administration, Funding acquisition, Writin – review & editing, Supervision.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Postgraduate Research & Practice Innovation Program of Jiangsu Province (Grant No. KYCX24_0335).

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during the current study are not publicly available. However, they are available from the corresponding author on reasonable request.

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