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Does the Concept of Green Development Promote High-Quality Urban Development?—An Empirical Analysis Based on the Pilot Policy of the “Zero-Waste City” in China

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Abstract: Since 2019, eighteen major ministries and commissions, including the National Development and Reform Commission, have launched trials for a “zero-waste city”. Shenzhen, Baotou, Tongling, and 16 other cities and regions have entered the practical operation stage, and the significance of the economic effect of the policy pilot needs to be tested through empirical evaluation. This study systematically gathers time series data from 281 prefecture-level cities in China from 2005 to 2022 and constructs an innovative experimental framework for the construction of a zero-waste city. It implements a series of rigorous robustness testing procedures using the difference-in-differences (DID) method to scientifically and objectively measure the actual effects of waste-free city construction strategies in promoting the city’s social development along a high-quality development path. This study provides deep insights into the zero-waste city construction strategy as a strong driving force. Our results indicate that the high-quality development stage has a positive impact on the city as a whole that cannot be ignored. At the same time, in-depth analysis shows that this strategy exhibits strong regional differences in the process of promoting high-quality urban development. For the two core regions of eastern and central China, the implementation of zero-waste city policies has significantly accelerated the pace of high-quality development, and further analysis reveals that, compared with the developed eastern region, the implementation of this policy in the central region has achieved superior results in terms of high-quality development. Third, the benefits of waste-free city policies are related to the economic bases of cities, the number of green patents granted, national policies, geographical location, and other factors.

Keywords: zero-waste city; policy evaluation; difference-in-differences model; high-quality development of society



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1. Introduction

China produces a significant proportion of global solid waste and is one of the major solid waste producers; its annual solid waste production has increased to exceed the 10 billion ton mark, while its total cumulative storage has increased to between 60 and 70 billion tons. Moreover, China plays a key role in global environmental protection. Despite China’s noteworthy economic expansion, fueled by its reform and opening-up policies, it still needs to achieve ecological sustainability and high-quality development [1]. In 2012, the 18th National Congress of the Communist Party of China established “Beautiful China”, marking the integration of urban economic prosperity and ecological civilization construction. This has been transformed into a comprehensive systematic project requiring strategic planning and in-depth implementation. According to public information from China’s Ministry of Ecology and the Environment, China’s national solid waste discharge reached 1.55 billion tons in 2018, 3.543 billion tons in 2019, and 3.68 tons in 2020. In recent years, the current cumulative stockpile of all types of solid waste has reached about 60–70 billion tons, with an annual generation of nearly 10 billion tons, a figure that has been growing year by year. The need for a zero-waste urban policy cannot be ignored. In this context,

the effective use of solid waste, reductions in solid waste generation, and the resolution of the problem of historical solid waste to ensure a virtuous cycle among the urban economy and ecology have attracted the attention of various players. China's zero-waste city pilot policy constitutes a key institutional framework and a form of strategic guidance that could promote the construction of a sustainable green circular economy system, accelerating the country's transition to a more environmentally friendly economic model.

Promoting the zero-waste city pilot is not only conducive to environmental protection; it is also the inevitable path along which China will move towards high-quality and sustainable development. China is actively using the waste-free city policy as a springboard for transformation and is pushing for profound changes in its economic model in a low-carbon, highly circular, and broadly inclusive direction. After the General Office of the State Council launched the "Garbage-Free City" in 2018, 11 cities and five special zones, including the Xiongan New Area in Hebei Province, were selected in 2019 as the first regions of transformation in the country to lead the demonstration of innovative green economy practices, alongside Shenzhen, Baotou, and Tongling. By 2024, the implementation of this policy will be greatly extended to include a total of 109 cities and regions, such as Shanghai and Chongqing. These pilot units are widely dispersed throughout the economic map of eastern, central, and western China, forming a nationwide pilot network.

High-quality and sustainable economic and ecological development will be the focus in China's "14th Five-Year Plan" and beyond. The government's strategic restructuring of its environmental policies will significantly promote the optimization and construction of local ecosystems and the green transformation of economic growth, demonstrating the firm promotion and achievement of sustainable development goals. In the short term, the Chinese government's concern for the environment is likely to cause some regional industries to suffer, leading to an economic downturn. Therefore, if the positive effects of zero-waste urban policies can be verified, the practical problem of high-quality urban development can be objectively solved.

This study has multiple strengths in its contribution to the literature. (i) It innovatively introduces the integration of an advanced index evaluation tool and entropy method, which significantly enhances the accuracy and scientific utility of the evaluation of the level of high-quality development within urban social conferences. (ii) By constructing a multi-stage DID model to test the policy mechanism of waste-free cities (a quasi-natural experiment), the government can objectively evaluate the effectiveness of the policy, identify existing problems and deficiencies in a timely manner, make feedback-based adjustments to the policy based on the results of the assessment to ensure that the policy objectives are achieved, and formulate countermeasures in advance to reduce the uncertainties and risks in the process of policy implementation. (iii) Through the construction and implementation of the difference-in-differences (DID) model, this study systematically analyzes the internal correlation between the environmental protection policies of the Chinese government and the effects demonstrated in the multi-city pilot practice, providing valuable theoretical guidance and a practical reference for the optimization of the effectiveness and guiding role of government policy.

This paper is arranged as follows: the second section is devoted to a review of the relevant literature and an in-depth discussion at the theoretical level; the third section carefully constructs our empirical research method; the fourth section presents our research results in detail, supplemented by an in-depth analysis and discussion; finally, the fifth section contains our conclusions and suggestions for countermeasures.

2. Literature Review and Theoretical Analysis

2.1. Literature Review

2.1.1. Research on High-Quality Urban Development

In the top-level blueprint of China's urban development strategy, high-quality development is clearly emphasized, and it covers not only the promotion of the steady and sustained growth of the economic system but also the sustainable prosperity of the environ-

mental and ecological fields [2]. It is a multidimensional concept. In academic circles, although domestic and foreign scholars hold multiple perspectives and opinions on the core essentials of high-quality urban development, they generally focus on three dimensions: a macro-system, meso-construction, and micro-operation. The first strategy is to carefully build a systematic macro-framework for high-quality urban development. It is generally recognized in this field that urban economic growth is an important cornerstone and direct driving force for high-quality development. For example, Zhao Jingmei (2023) proposed that high-quality economic development should include several research dimensions, such as innovation-driven development, green development, and coordinated development [3]. Subsequently, a large number of researchers have created multi-dimensional regional economic evaluation index systems, focusing on aspects such as economic, innovation-driven, and green development. The main researchers include Deng Zhituan (2024), Yang Yongfang, and Wang Qin (2024) [4,5]. The second strategy is to focus on the middle level of urban development and explore its role in high-quality urban development. The next aspect is the impact of meso-construction on high-quality urban development. Recent academic discussions have gone beyond a single dimension and instead focused on how multiple factors, such as green finance mechanisms and energy efficiency improvement strategies, are interweaved to build a dual synergistic framework (Liu et al., 2021) (Ding et al., 2021) [6,7]. Scholars believe that the sustainability of the urban environment is a central and indispensable indicator in measuring and judging the effectiveness of high-quality urban development. Liu X. (2023), Liu Z. (2023), and others have found that the improvement of environmental quality and the substantial mitigation of pollution problems in China mark a profound shift in the environmental protection policy framework and embody efficient implementation. In particular, for each percentage point increase in the government concern index, the level of environmental pollution is correspondingly reduced by 0.13 units [8,9]. Additionally, as discussed by Ma Zhen (2024), the all-round deployment of the smart city development strategy has greatly strengthened the rapid response mechanism and inherent resilience of the city to cope with complex challenges [10]. The third aspect is micro-operation within high-quality urban development. Driven by the vision of “Beautiful China”, the Chinese government is committed to achieving a strong synergy between the ecological environment and the economy, and environmental policy has thus become a key lever to promote economic transformation and upgrading to a higher level of development. Its effectiveness and its core role in the process of transformation have become major topics of academic debate and in-depth analysis. Yu Yongze et al. (2020) also provided an in-depth analysis of the specific effects of environmental target constraints set by local governments in terms of improving the quality of urban economic development, thus highlighting the indispensable role of environmental policy in guiding and shaping the evolution of the urban economy [11]. Liu et al. (2021) verified the role of government environmental regulations in the sustainable economic growth of key regions by constructing a dynamic spatial Durbin model [12].

To date, scholars from various countries have analyzed the role of institutional construction and other factors in high-quality urban development from the perspective of the economy and ecology. There is a trend towards more quantitative research, but most of the research works focus on the impact of the financial system on the economy, and, when discussing the multi-dimensional evaluation system for high-quality urban development, the recognition of its importance in various fields shows significant differences. This study adopts both economic and ecological aspects, focusing on the integration of five concepts, and builds a high-quality development assessment framework. It then provides an in-depth analysis of the far-reaching and lasting effects of green development strategies on urban development.

2.1.2. Effects of City Policy on High-Quality Urban Development

The relationship between urban policies and economic development has received increasing attention. There are two main research trends related to this study. The first

encompasses a series of macro-levels, such as smart city construction and the in-depth discussion of how environmental protection measures such as waste-free cities and economic development form a positive interaction and synergy. Tao, M.M. (2024) et al. used the entropy balance DID method to explore the value of energy conservation and emission reduction measures in the zero-waste city policy [13]. Liu Zhixiong et al. (2024), through a series of rigorous empirical analyses, achieved a breakthrough in revealing the core role of environmental protection policies in driving sustainable economic growth. This not only solidifies the stable foundation of the economic system but also exerts a positive effect in guiding the economy to a higher-quality development stage [14,15]. Wu Jie et al. (2024) found that environmental quality exerts an intermediate and threshold effect on economic development [16]. The other research trend focuses on the zero-waste city's construction itself, from solid pollutant discharge and industrial waste to other aspects, for an in-depth exploration of its relationship with urban economic development. From the perspective of foreign studies, as early as 2005, some scholars used system dynamics modeling to predict municipal solid waste production in rapidly developing urban areas, emphasizing the importance of predicting the trend of waste production for effective waste management strategies (Brian Dyson, Ni-Bin Chang, 2005) [17]. Pao et al. (2011) conducted a study on Russia and verified that zero-waste city policies can reduce emissions without negatively affecting economic development [18]. Domestic scholars have focused on the socioeconomic development backgrounds of specific Chinese cities and explored the complex correlations between this aspect and industrial waste emissions, emphasizing the importance of targeted measures for environmental sustainability and high-quality economic development (Zhai, 2020) [19]. He et al. (2021) innovatively considered the path of city construction as the core pillar of smart city construction; their research takes the in-depth study of the effectiveness of environmental governance as its entry point and reveals that environmental sustainability is an indispensable factor in promoting the economy towards high-quality growth. Its internal mechanism and positive impact occupy a pivotal position in the regional economic development strategy. Their work emphasizes the close relationship between the two, which complement each other with co-existence and co-prosperity [20]. Tang et al. (2023) emphasize the key path to stimulating green technology innovation and then consider technological innovation as an engine to promote sustainable economic growth. This process highlights the sustainable development concept of both environmental protection and the economy [21]. The waste-free city policy is not only a concept of green living but also a low-carbon economic model that focuses on green development. Li Jiasheng et al. (2024) demonstrated that environmental pollution has a negative impact on the ecological economy [22].

Overall, the existing data profoundly elucidate the multi-dimensional positive effects of the city strategy in accelerating the process of urban intelligence, promoting the fundamental improvement of environmental quality, and effectively curbing pollutant emissions. Additionally, it can promote green technology innovation and ultimately achieve high-quality sustainable economic growth. However, both domestic and foreign scholars conduct research from the perspectives of the macro-construction of measurement systems. Single city/urban agglomeration, an industry in a city or policy formulation (Ma Ran et al., 2024) [23], and the ways in which zero-waste city policies lead to regional differences in economic development among cities are still unclear in the current research field.

2.2. Research Hypothesis

2.2.1. Effects of Waste-Free City Policy on the High-Quality Development of Urban Society

The importance of the green development concept is obvious. Specifically, the city has become an important factor in the transformation of the urban green economy, and its implementation has directly led to a sharp decline in solid waste emissions. This initiative is not only a landmark action to promote the transformation of the economy in a low-carbon and environmentally sustainable direction, but also a core pillar of the strategic framework of urban sustainable development, leading the city towards a more green,

efficient, and harmonious development era. The grand blueprint of city construction indicates that the focus of environmental governance will move towards a more refined dimension, not only limited to overall improvement at the macro level but extending to the micro level. Thus, it is necessary to carry out detailed analysis and accurate positioning of the governance object, guarantee important ecological functions, continuously optimize environmental quality and safety, and implement strict and effective environmental management policies. This will also encourage enterprises to enhance their scientific research and innovation capabilities, promote green transformation, and improve their resource utilization. The transformation of the urban green economic structure will become a key force in driving the urban economy towards high-quality development, and the significant improvement of the ecological environment's quality will be a continuous driving force in promoting the realization of high-quality development and the improvement of environmental quality. Through economic development and environmental improvement, all dimensions of high-quality urban social development will be optimized and improved. In light of this, we propose the following.

H1: *The concept of green development plays a significant role in promoting the high-quality development of urban society in the process of implementing the waste-free city policy.*

2.2.2. Effects of Garbage-Free City Policy on Regional Differences in High-Quality Social Development

In view of the significant heterogeneity among the strategic positioning and development levels in the geographical distribution of Chinese cities, in the process of implementing the city policy, an unforeseen consequence may be the disregard of travel behavior. This exerts a complex effect on urban society in its move towards a higher-quality development stage, exhibiting obvious differences between different regions, and scholars have proposed a decreasing trend of “one in the east, one in the middle, one in the west” and “coastal to inland” [24]. Because pilot cities without waste city policies also show an “east–middle–west” distribution trend in terms of location, and different cities have differences in their economic foundations, policy inclinations, ecological status, and other aspects, we propose the following.

H2: *The effect of the waste-free city strategy in promoting high-quality social development shows significant regional heterogeneity.*

H3: *The stimulus effect of the waste-free city policy is more obvious in cities with better basic conditions.*

3. Model Design

3.1. Index Construction and Level Measurement of High-Quality Social Development

Regarding the development of urban social quality, no single perspective can capture the overall level of urban social development. There is a close interconnection and mutual influence between the environment and the economy. On the one hand, economic development is often accompanied by an increase in environmental pressure, such as resource consumption and pollution emissions; on the other hand, a favorable environmental situation can provide strong support for economic development, which has a direct impact on the quality of human life and the ability of society to develop in a sustainable manner. Governments and all sectors of society often take the environment and the economy into account when formulating and implementing relevant policies. Therefore, this study is based on economic and ecological development. The main data come from 281 prefecture-level cities with a time span of 2005 to 2022. The entropy evaluation method is the main method used during this study. After the above series of preparatory work is completed, a comprehensive evaluation system is built, including 12 s-level key performance benchmarks and 21 specific and measurable evaluation benchmarks. The scientific distribution of the indicators at each level and their corresponding weights are accurately calculated. The quality development index of the city is obtained (Table 1).

Table 1. Evaluation index system for high-quality social development.

Primary Indicators	Secondary Indicators	Specific Indicators	Unit of Measurement	Indicator Attribute	
Innovative development	Input in science and education	Science and education input/fiscal expenditure	%	+	
		Education input/fiscal expenditure	%	+	
Coordinated development	Patent level	Number of patents granted	EA	+	
	Financial development	Financial deposit balance/financial loan balance	%	+	
Open development	People’s livelihoods	Per capita income	¥	+	
	Industrial structure	Proportion of tertiary industry	%	+	
	Summary of foreign investment	Utilization of foreign capita	Hundreds of millions of USD	+	
	Overview of foreign companies	Total output value of foreign-funded enterprises	Hundred million CNY	+	
Green development	Discharge of three waste types	Number of foreign-funded enterprises	EA	+	
		Industrial wastewater discharge/industrial output value	Ton/ten thousand CNY	-	
		Industrial sulfur dioxide emissions/industrial output value	Ton/ten thousand CNY	-	
		Industrial smoke (dust) emissions/industrial output value	Ton/ten thousand CNY	-	
		Sewage treatment	Comprehensive utilization rate of general industrial solid waste	%	+
			Centralized treatment rate of sewage treatment plants	%	+
	Social welfare		Harmless treatment rate of household garbage	%	+
		Garden green area	Ha.	+	
Green coverage rate of built-up areas		%	+		
Shared development		Park green area	Ha.	+	
		Consumption of retail goods/GDP	%	+	
	Government burden	Fiscal expenditure/revenue	%	+	

3.2. Model Design and Variable Selection

3.2.1. Model Evaluation

The multicollinearity problem was thoroughly tested using the VIF method (Table 2). The variable had a VIF value below 10, which effectively proved that the multicollinearity in the research model was relatively small.

Table 2. Multicollinearity test.

Variable	VIF
Fin	2.52
Ind	2.13
Hre	1.79
urban	1.6
Gov	1.39
ZWC	1.02
Mean VIF	1.74

3.2.2. Model Design

The main data in this study come from 281 prefecture-level cities, covering the period of 2005 to 2022. The main method used in this study is entropy evaluation. We design an innovative quasi-natural experimental analysis framework focusing on zero-waste city policy pilots. Under this framework, we carefully distinguish between the cities covered by the pilot policy (experimental group) and the cities not covered by the pilot policy (control group), and we adopt established comparative analysis techniques for in-depth research. Currently, the city pilot is divided into two stages: the first included 16 cities and regions at the end of 2018, and the second included 29 provinces and municipalities in April 2022, with more than 100 prefecture-level cities eventually included to launch the pilot. Due to the short pilot period in 2022, relevant indicator data could not be collected. To ensure the scientific nature of the experiment, in this study, the first cities to receive the city policy trial were set as the experimental group, and cities that were not given the opportunity to participate in the early stage of the policy pilot became the natural control group. Due to the differences in the timing of the pilot policies in different cities, based on the above grouping, and inspired by the research achievements of Liu Jia et al. (2021) and Guo Chengyu (2024) [25,26], we constructed the following DID model:

$$Squa_{it} = \beta_0 + \beta_1 ZWC_{it} + \theta X_{it} + \mu_t + \gamma_i + \varepsilon_{it} \quad (1)$$

In this formula, t is the year, i is the city, $Squa$ is the quality of the social development of the i city in t year, μ_t is the fixed effect of time, and ε is the error value. X_{it} is the control variable, which covers a wide range of dimensions, such as the urbanization process, government regulation, industrial structure layout, human capital accumulation, and financial deepening degree.

- (1) Explained variables: high-quality social development. This study uses the advanced entropy weight method to conduct an unprecedented and detailed analysis and the quantitative reconstruction of the five core first-level evaluation dimensions. It subdivides them into a comprehensive evaluation system containing 12 s-level key performance benchmarks and 21 specific measurable evaluation benchmarks. This system not only comprehensively covers the key areas and core elements of high-quality urban social development but also realizes the accurate characterization and dynamic monitoring of high-quality urban development through scientific and rigorous quantitative means, providing strong data support and a decision-making reference for policy formulation and effect evaluation (Table 1).
- (2) Core explanatory variable: the concept of green development, i.e., the pilot effect of the city policy (ZWC), using the process of DID. In this study, the explanatory variable refers to whether a city conducts a city policy pilot. Consistent with the treatment of the explanatory variable in terms of time, before the implementation of the pilot policy, a standardized assignment strategy is adopted, which assigns all cities a base value of 0 before the pilot year, and the pilot year is 1.
- (3) Control variable: When constructing an analytical framework to explore the multi-dimensional drivers of high-quality social development, several key urban develop-

ment characteristics are carefully selected as control variables and these factors are taken into consideration.

① Urbanization level (urban): The purpose of this study is to systematically analyze the process of urbanization, to accurately measure the level of urbanization as a starting point, and to analyze its effect on high-quality development and organization management. The proportion of the urban population/the total number of permanent residents in prefecture-level cities is a quantitative index (C1 in the following article). ② Degree of government intervention (Gov): The allocation of a specific proportion of government financial expenditure to smart city and waste-free city construction projects, especially for solid waste management investment initiatives, has significantly promoted the cultivation and growth of the urban green economy system. In the in-depth analysis of the internal driving force of social progress and high-quality development, this study introduces an unprecedented quantitative perspective, i.e., using the dynamic change in the proportion of government financial input to the regional GDP as a key indicator to measure the intensity and effect of government intervention in economic and social development (C2 in the following text). ③ Industrial structure (Ind): Secondary and tertiary industries can reflect the local strategy for industrial development and can be used to study the practice of green development. The value added of the tertiary industry/gross regional product is a quantitative indicator (C3). ④ Human capital level (Hre): In the relevant studies on economics and management, the human capital level is regarded as an important factor affecting enterprise performance, economic growth, and social development [27,28]. College students are the key factor in promoting local innovation and development and human resources; the ratio of college students to the total population at the end of the year is a quantitative index (C4 is used later). ⑤ Financial development degree (Fin): Promoting the efficient conversion of savings funds into investment momentum is a core strategy to stimulate technological innovation and the potential of industrial upgrading, and it has a far-reaching impact on the overall development of the financial system. It can lead the industrial structure to a new stage of unprecedented efficiency and harmonious symbiosis, which not only leads to the rapid rise of emerging industries but also opens up a broad space for the significant improvement of the overall well-being of society [29]. The balance of deposits and loans of financial institutions at the end of the year/gross regional product is a quantitative indicator (C5 is used later).

3.3. Data Source and Explanations

The selected samples have a wide time span and strong consistency, and they cover the key stage of the implementation of the target policy, meaning that they are highly representative and possess strong analytical value. The dataset of this study is composed of high-quality data from authoritative statistical databases such as the China Urban Statistical Yearbook. At the same time, we also integrate the detailed information publicly disclosed by the municipal statistical bureau over the years to ensure the diversity and authority of the data sources and the full coverage of the research topic. To address the small amount of missing data in 2022, this study adopts the scientific and reasonable interpolation method.

4. Results and Discussion

4.1. Basic Regression Analysis

Table 3 shows the descriptive statistics of the data and Table 4 shows the regression results of Equation (1). (1) As regression results without control variables, the ZWC variable showed a clear positive effect, whose strength was quantified as a correlation coefficient of 0.010, and the positive association was statistically significant (p -value less than 0.05). This study adds five control variables in columns (2) to (6) sequentially: the urbanization level, the government intervention level, the industrial structure, the human capital level, and the financial development level. Data analysis reveals that the coefficient of the ZWC variable shows statistical significance, and the coefficient values are between 0.011 and 0.012.

The foregoing analysis strongly confirms the significant catalytic role of zero-waste city policies in moving pilot urban societies towards a high-quality development stage.

Table 3. Descriptive statistics.

Variable	N	Mean	SD	Min	Max
Score	4947	0.045	0.057	0.010	0.598
urban	4947	0.527	0.169	0.114	1.001
Gov	4947	0.179	0.100	0.043	1.936
Ind	4947	0.406	0.101	0.111	0.839
Hre	4947	0.020	0.027	0.000	0.225
Fin	4947	2.340	1.176	2.019	21.302

Table 4. Basic regression results.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Score	Score	Score	Score	Score	Score
ZWC	0.010 *** (0.003)	0.011 *** (0.003)	0.012 *** (0.003)	0.012 *** (0.003)	0.012 *** (0.003)	0.012 *** (0.003)
Urban		0.021 *** (0.004)	0.021 *** (0.004)	0.020 *** (0.004)	0.020 *** (0.004)	0.020 *** (0.004)
Gov			0.036 *** (0.004)	0.037 *** (0.004)	0.038 *** (0.004)	0.037 *** (0.005)
Ind				−0.037 *** (0.006)	−0.037 *** (0.006)	−0.038 *** (0.006)
Hre					0.066 *** (0.025)	0.067 *** (0.025)
Fin						0.000 (0.000)
_cons	0.581 *** (0.001)	0.573 *** (0.002)	0.568 *** (0.002)	0.582 *** (0.003)	0.581 *** (0.003)	0.580 *** (0.003)
idfix ¹	yes	yes	yes	yes	yes	yes
yearfix ²	yes	yes	yes	yes	yes	yes
N	4947.000	4947.000	4947.000	4947.000	4947.000	4947.000
R ²	0.280	0.284	0.294	0.300	0.301	0.301

Scheme: *** $p < 0.01$. ¹ idfix stands for fixed urban benefits; ² yearfix stands for year fixed benefits.

4.2. Parallel Trend Test

When using a differential model to evaluate the policy effect, ensuring the establishment of the parallel trend hypothesis is essential to guarantee the effectiveness of the model. In view of this, this study adopts the rigorous strategy of event study to analyze the dynamic effects of zero-waste city pilot policies over time [30]. The model is established as shown in Equation (2):

$$Squa_{it} = \partial_0 + \sum_{j=-3}^{j=3} \delta_j ZWC_{it-j} + \sum bX_{it} + \partial_i + \lambda_t + \varepsilon_{it} \quad (2)$$

ZWC_{it} , j represents the meaning of the virtual variable of the j year before and after the implementation of the waste-free city pilot policy. In the process of processing group city i in the $t-j$ year of the pilot period, the variable is kept as 1; otherwise, it is 0. X_{it} represents the other control variables, with α_i , β_t , and ε representing city fixed effects, time fixed effects, and error terms, respectively.

The core concept of parallel trend hypothesis testing is to ensure that two groups are close at a high level of high-quality development, which should be reflected in a high degree of coordination in time. In other words, the development rate and direction of the two should show consistency and convergence before the policy intervention. Therefore, this constitutes an indispensable baseline consistency test standard in the evaluation of

policy effects. By the time the policy is implemented, the two types of cities will show a significantly differentiated evolution trend. In view of the unique phased characteristics in the implementation process of zero-waste city policies, this study adopts the event analysis method, focuses on cross-period analysis from the first three years to the last three years of policy implementation (specifically excluding the year before policy implementation as a static reference), builds a highly targeted interaction model consisting of year and policy dummy variables, and implements parallel trend tests.

Figure 1 illustrates the parallel trend test. Before there is a concrete policy research process, the fluctuation of the regression coefficient is not significant, and the quality indicators converge before the pilot mapping of the city, i.e., no statistically significant deviation occurs. This result not only strengthens the foundation of the parallel trend hypothesis but also further confirms the scientific validity of the study design. At the important node of the one-year implementation of the policy pilot, the regression coefficient of the policy dummy variable achieves a qualitative leap, not only in its numerical value but also in its statistical significance, reaching an unprecedented level. Henceforth, the regression coefficients of the policy dummy variables in each assessment cycle maintain a steady, high significance level and continue to grow positively. Compared with the control group, the experimental cities show a more significant and sustained trend of quality improvement. Through the parallel trend verification, both groups of city quality indicators are improved over time.

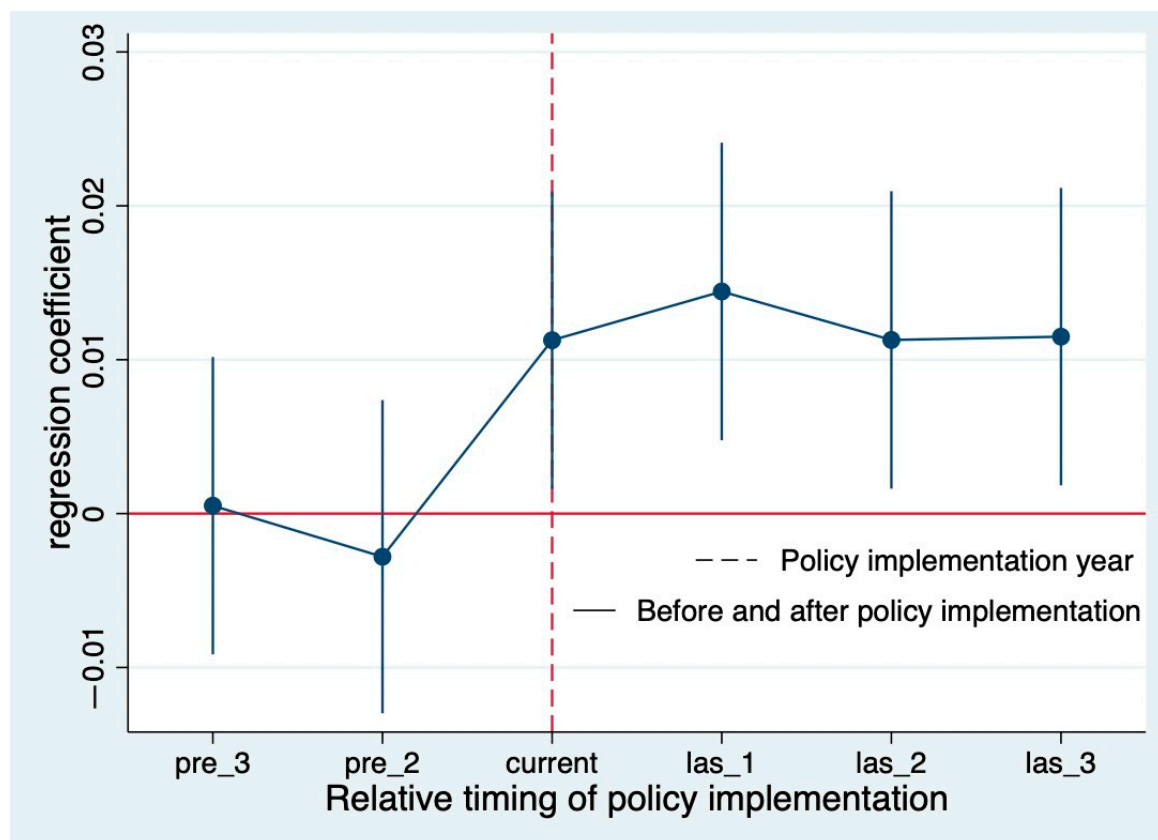


Figure 1. Parallel trend test.

4.3. PSM-DID

Considering that the selection of the pilot list of cities may not be completely random, in order to overcome the possible bias problem in the selection of the pilot cities, this study introduces the propensity score method. It then carries out fine rematching processing for the control cities, followed by performing PSM-DID regression analysis again on this basis. The PSM steps are as follows: variables with city characteristics are taken as the covariate

group, and logit regression is performed on the covariate group based on whether they are included in the pilot city list. Propensity score values are calculated according to the regression results, and cities with the most similar characteristics to the experimental group are selected from the control group as the control group based on the 1:2 nearest neighbor matching method. Table 5 shows the conclusions of the propensity score matching balance test, and Figure 2 shows the difference before and after matching.

Table 5. Propensity score matching: the results of the balance test.

Variable		Mean		% Bias	% ReducedBias	T	p
		Treated	Control				
C1	Unmatched	0.68031	0.52144	97.4		12.51	0.000
	Matched	0.67902	0.6823	−2	97.9	−0.19	0.849
C2	Unmatched	0.14487	0.18027	−28.5		−4.64	0.000
	Matched	0.13491	0.13891	−3.2	88.7	−0.76	0.501
C3	Unmatched	0.43672	0.40532	27.3		4.08	0.000
	Matched	0.43566	0.43223	3	89.1	0.28	0.779
C4	Unmatched	0.02585	0.02022	23.5		2.75	0.006
	Matched	0.02584	0.02567	0.7	96.9	0.06	0.949
C5	Unmatched	2.6309	2.3293	21.9		3.37	0.001
	Matched	2.6162	2.5542	4.5	79.4	0.41	0.681

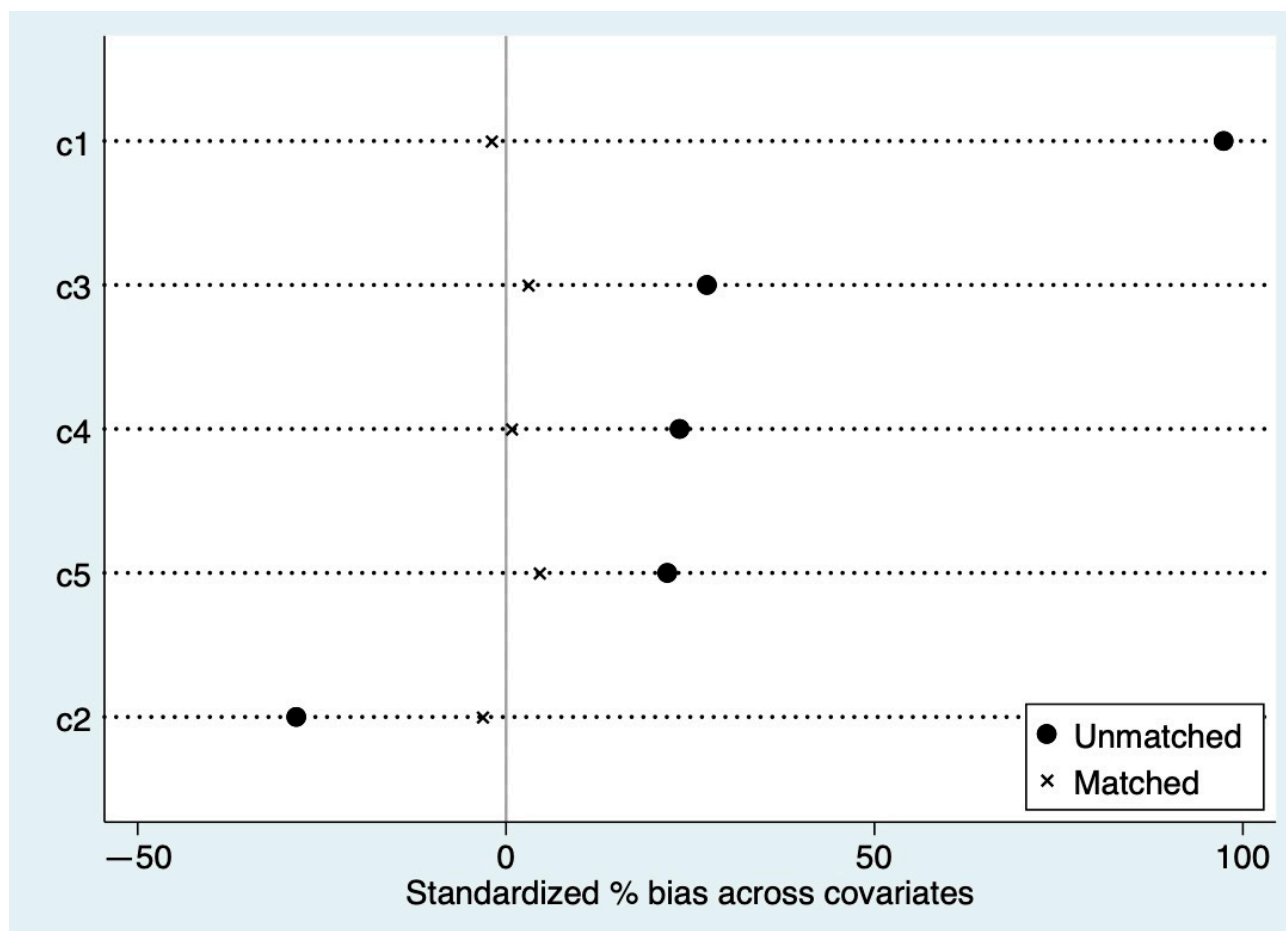


Figure 2. PSM-DID test results.

After the in-depth analysis of the specific differences between the groups, and after pairing adjustment, there is no difference between the two groups. After accurate sample screening through the propensity score matching method, we begin the process of regression analysis, and the final research conclusions are listed in Table 6. Through the meticulous verification process, we confirm that, on the basis of the full control of potential confounding variables, the dummy variable of the city pilot policy still shows a significant positive effect, and its significance level is firmly maintained at a very high standard of 1%. This further validates the scientific nature of the policy effect assessment.

Table 6. Robustness test results.

Variable	(1)
	Score
ZWC	0.016 *** (0.005)
c1	0.004 (0.017)
c2	0.106 ** (0.050)
c3	0.010 (0.021)
c4	0.407 *** (0.107)
c5	0.002 (0.002)
_cons	0.544 *** (0.012)
N	345.000
R ²	0.491
Idfix	yes
Yearfix	yes

Scheme: ** $p < 0.05$, *** $p < 0.01$.

The % bias and % reduced bias reflect the degree of sample bias before and after matching and the percentage of reduction.

4.4. Placebo Test

After the parallel trend test of the multistage difference model, we further examined whether the two groups were potentially disturbed by external policies or random factors in the post-intervention period. To test for this possibility, we used 500 random samples. By randomly generating a pseudo-experimental group and pseudo-policy dummy variables for the placebo test, 500 groups of regression coefficients were finally obtained, and placebo test diagrams, as shown in Figures 3 and 4, were drawn. Figure 3 shows that, after randomization, the coefficient is close to 0, and the p-value is essentially above 0.1. The estimation results of the actual observed sample data, represented by the vertical dashed line, deviate from the main distribution range of the random sample's estimated coefficients. This indicates that the random sample estimation results are not significant and that there is a large difference compared to the real sample estimation results, signifying that the model has successfully passed the placebo test, excluding the influence of other policy or random factors.

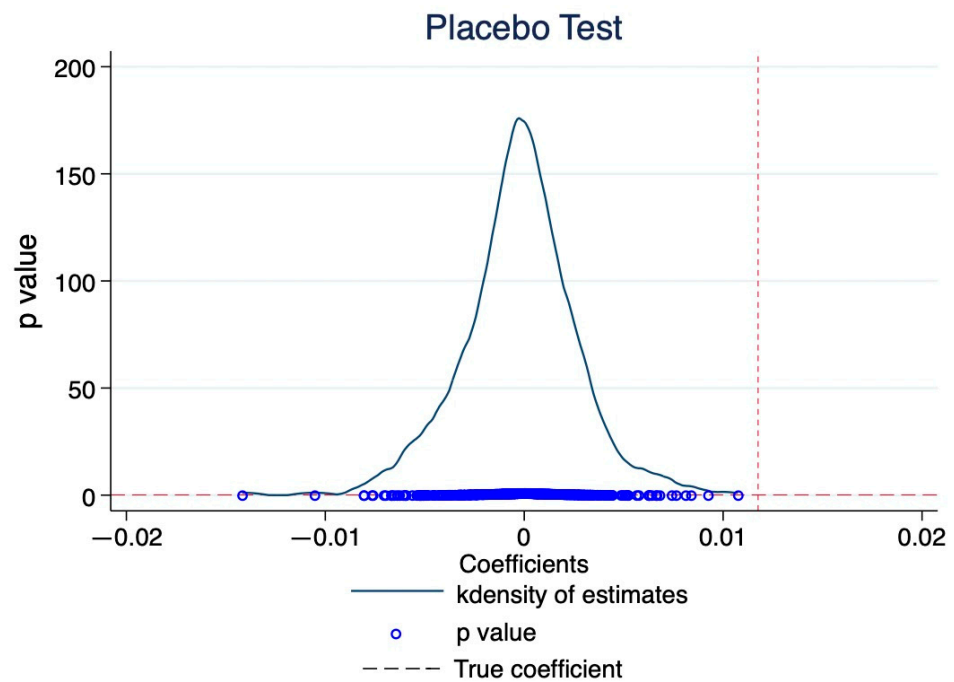


Figure 3. Placebo test results A.

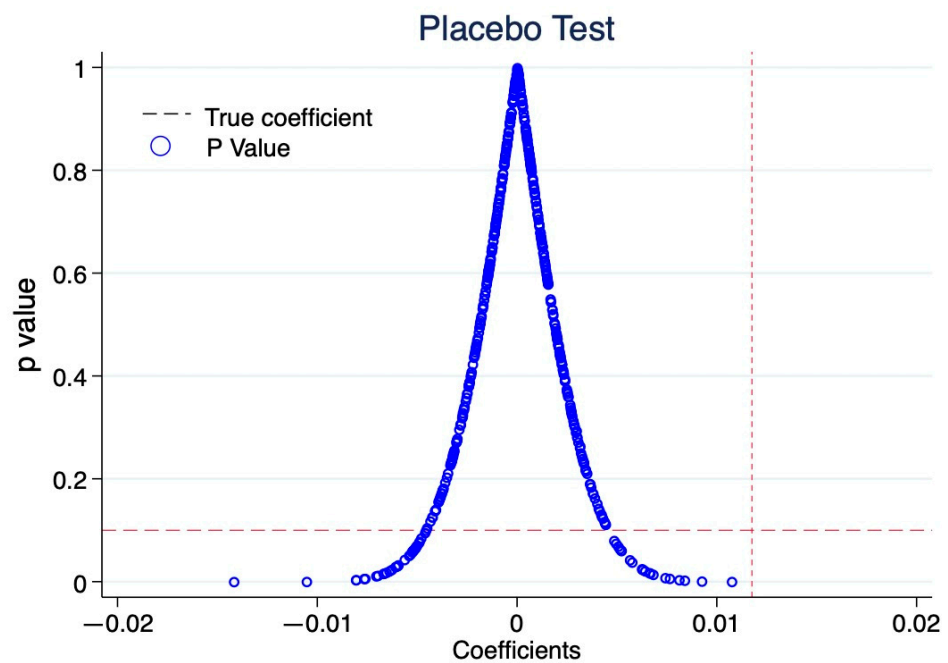


Figure 4. Placebo test results B.

4.5. Heterogeneity Analysis

It is worth noting that, due to the significant differences in the policy implementation environment, geographical location, economic basis, and other aspects of cities, the implementation effect of waste-free city policies shows significant heterogeneity and diversity. Therefore, this study established a heterogeneity test model, as shown in Equation (3), based on the geographical location:

$$Sque_{it} = \beta_0 + \left(\beta_1 + \sum_{j=1}^{j=n-1} \gamma_1 D_{jt} \right) ZWC_{it} + \sum bX_{it} + \partial_i + \lambda_t + \varepsilon_{it} \quad (3)$$

This study innovatively discusses the all-round shaping effect of the zero-emission city policy on urban development. As the basic aspects of social development, such as the inter-city governance capacity, green innovation technology, the number of universities and students, and industrial structure, are different across cities, the heterogeneity of cities in different regions should be studied. This process helps us to build a more accurate policy implementation framework and strategy. Based on the division of the policy pilot areas, this study divides the urban samples into three categories, i.e., eastern, central, and western cities, and the sub-sample regression analysis results are presented in Table 7. There are two reasons for this. First, eastern coastal cities are economically developed and technologically advanced, but their land resources are scarce and their environmental capacity is limited. The implementation of city policies in eastern cities is more difficult and requires a higher technical and management level for support. In addition, compared with other regions, the industrial structure construction and environmental governance mechanisms of eastern cities show remarkable maturity and stability, and the role of city policy in promoting industrial transformation and upgrading is limited. Secondly, central cities generally occupy the core geographic locations of the country, connecting the east and west and running through the north and south, with unique geographical advantages. At the same time, central cities are often at the stage of accelerated industrialization and urbanization. Compared with the eastern coastal cities, they not only have more room for improvement in their ecological and environmental management capacity but also have a more diversified industrial structure. Compared with the western regions, their economic foundations and development speeds are more advantageous.

Table 7. Regression results of urban regional heterogeneity.

Variable	Region		
	Eastern City	Central City	Western City
ZWC	0.010 * (0.006)	0.013 *** (0.003)	−0.005 (0.008)
c1	0.061 *** (0.009)	−0.016 *** (0.004)	−0.010 (0.008)
c2	0.044 *** (0.014)	0.065 *** (0.006)	−0.012 ** (0.005)
c3	−0.057 *** (0.017)	−0.010 * (0.005)	0.004 (0.010)
c4	0.073 (0.062)	0.016 (0.024)	−0.087 * (0.047)
c5	0.001 (0.001)	−0.001 *** (0.000)	−0.000 (0.001)
_cons	0.550 *** (0.007)	0.594 *** (0.003)	0.023 *** (0.005)
yearfix	yes	yes	yes
idfix	yes	yes	yes
N	1755.000	1915.000	1241.000
R ²	0.338	0.483	0.280

Scheme: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

In this study, the sample was divided into large, medium, and small cities according to the sizes of the pilot policy cities, and the sub-sample was further regressed. The results are shown in Table 8. It can be seen that the promotion effect of the no-waste city policy on the high-quality development of society in small- and medium-sized cities is stronger than that in large cities. There may be three reasons for this. Firstly, in terms of government management and policy implementation, small- and medium-sized cities are relatively easy to implement and manage due to their small size. Moreover, the policy can reach all levels faster, and less resistance and fewer challenges are encountered in the implementation process, so the effect of the policy can be seen faster. Second, in terms of solid waste generation and treatment capacity, small- and medium-sized cities

produce relatively little solid waste, and their solid waste treatment capacity is relatively well-matched. This enables the timely and effective treatment of solid waste and reduces environmental pollution and the waste of resources. At the same time, small- and medium-sized cities have greater potential for solid waste resource utilization. As the amount of solid waste generated is moderate, it is easier to achieve the classification and collection of solid waste, resource utilization, and recycling, thus improving the efficiency of resource utilization. Third, in terms of the industrial structure and green transformation, the industrial structures of small- and medium-sized cities are relatively simple, with low transformation costs. They are dominated by light industry, agriculture, and other industries, which are relatively easy to transform and upgrade in a green manner. Through policy guidance and support, the greening and low-carbon development of these industries can be achieved more quickly.

Table 8. Regression results for city size heterogeneity.

Variable	City Scale		
	Large City	Medium-Sized City	Small City
ZWC	0.000 (0.023)	0.011 *** (0.001)	0.007 ** (0.003)
c1	0.070 * (0.036)	−0.007 *** (0.002)	−0.007* (0.004)
c2	−0.276 ** (0.139)	0.030 *** (0.004)	0.020 *** (0.003)
c3	−0.070 (0.060)	−0.012 *** (0.003)	−0.041 *** (0.006)
c4	0.267 ** (0.115)	0.014 (0.015)	0.037 (0.024)
c5	0.027 *** (0.006)	0.002 *** (0.000)	0.000 (0.000)
_cons	0.421 *** (0.039)	0.590 *** (0.001)	0.598 *** (0.003)
yearfix	yes	Yes	yes
idfix	yes	Yes	yes
N	378.000	1879.000	2690.000
R ²	0.617	0.708	0.362

Scheme: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.6. Mechanism Analysis

In order to verify whether the implementation of the waste-free city policy promotes the solid waste utilization rate and the number of green patents with regard to the high-quality development of the urban economy, this study takes the urban high-quality development index as the explanatory variable and carries out regression on the solid waste utilization rate and the number of green patents authorized, taking the logarithmic value, and the results are shown in Table 9. Columns (2) and (3) show that the solid waste utilization rate is significantly positive in the regression coefficients, indicating that the waste-free city policy improves the city's high-quality development level by increasing its solid waste utilization rate. Similarly, columns (4) and (5) show that the waste-free city policy has increased the number of green patents granted to cities, which in turn has increased the level of high-quality development.

Table 9. Regression analysis of intermediation mechanisms.

Variable	(1)	(2)	(3)	(4)	(5)
	Score	Lnz1	Score	Lnz2	Score
ZWC	0.012 *** (0.003)	0.118 ** (0.055)	0.012 *** (0.003)	0.292 *** (0.107)	0.011 *** (0.003)
Lnz1			0.002 ** (0.001)		
Lnz2					0.001 ** (0.000)
c1	0.020 *** (0.004)	0.201 *** (0.076)	0.020 *** (0.004)	1.279 *** (0.148)	0.019 *** (0.004)
c2	0.037 *** (0.005)	−0.183 ** (0.083)	0.037 *** (0.005)	−0.874 *** (0.161)	0.038 *** (0.005)
c3	−0.038 *** (0.006)	0.797 *** (0.110)	−0.039 *** (0.006)	−0.507 ** (0.214)	−0.037 *** (0.006)
c4	0.067 *** (0.025)	−1.195 *** (0.461)	0.068 *** (0.025)	−0.235 (0.895)	0.067 *** (0.025)
c5	0.000 (0.000)	0.018 ** (0.008)	0.000 (0.000)	−0.055 *** (0.015)	0.000 (0.000)
_cons	0.580 *** (0.003)	3.968 *** (0.055)	0.574 *** (0.004)	1.979 *** (0.107)	0.578 *** (0.003)
yearfix	yes	yes	Yes	yes	yes
idfix	yes	yes	Yes	yes	yes
N	4749.00	4749.00	4749.00	4749.00	4749.00
R ²	0.301	0.055	0.302	0.887	0.302

Scheme: ** $p < 0.05$, *** $p < 0.01$.

5. Conclusions and Policy Recommendations

5.1. Conclusions

Using cutting-edge data analysis techniques, this study innovatively introduces a complex system dynamics perspective to capture nonlinear interactions between variables. In the empirical analysis, this study eliminates the limitations of the traditional single model and creatively integrates a variety of advanced statistical methods, such as DID analysis, PSM-DID, and placebo tests. The results of this study firmly establish urban policies as the core tool driving urban society towards high-quality development. Moreover, the uniqueness, scientific nature, and non-reproducibility of the research conclusions are confirmed through a series of rigorous robustness tests. Through the heterogeneity analysis, it is established that the developmental effects of the zero-waste city pilot policy vary significantly among distinct regions. Specifically, especially in central cities, this effect is more pronounced. This correlation could be intimately tied to the advantageous geographical positioning of central cities, their convenient transport networks, and national policies aimed at bolstering the ascendancy of the central region. This finding provides a new perspective for the understanding of the implementation effects of zero-waste urban policies in different geographical contexts.

5.2. Policy Recommendations

Drawing from the aforementioned conclusions, specific countermeasures are as follows.

First, the current implementation scale and intensity of the city policy are still insufficient, and it needs to be further strengthened to fully realize its potential. First of all, it is crucial to accelerate the transformation of cities nationwide in pursuit of zero waste and lead the in-depth development of domestic waste treatment towards reduction and high-value resource recycling through technological innovation. Secondly, it is necessary to build a comprehensive and multi-dimensional policy support system, widely promote the green reconstruction of the urban industrial structure, and fundamentally inhibit the generation of solid waste. It is necessary to build a complete legal support system and an efficient supervision mechanism, which complement each other to ensure the normal pace

of construction so that the waste-free city will become a solid support and core engine to drive society towards a high-quality development stage.

Secondly, the path of urban development should deeply reflect its unique characteristics. The dual progress of economic prosperity and ecological civilization construction constitutes the most important aspect of high-quality social development. Cities should take their own economic foundations as a starting point to strengthen the evaluation and examination of policy results. The foundation for the construction of a city is solid thanks to the strong economic support system. The heterogeneity analysis clearly shows the outstanding performance in the central and eastern regions, which have achieved remarkable results, far exceeding expectations, and have become a benchmark for the promotion of regional green transformation and sustainable development. Therefore, all cities need to focus on the local economic foundations, promote financial funds for waste-free city construction projects, strengthen the support system for science and technology, and optimize the path for the cultivation and growth of scientific and technological talent.

Furthermore, government departments should also participate in the construction of waste-free cities on the basis of their functions. Ecological and environmental departments should participate on the basis of promoting the formulation of solid waste management policies, supervision and law enforcement, and assessment and evaluation. They should promote the standardization and construction of solid waste classification, collection, transfer, and treatment and disposal systems. Housing and urban–rural construction departments should be responsible for the construction and management of urban domestic waste treatment facilities, and they should promote the resourceful use of and a reduction in construction waste. The industry and information technology sector should promote the reduction, resourcing, and harmless treatment of industrial solid waste and support the development of industrial green manufacturing and a circular economy. Agricultural and rural sectors should shift their focus to the comprehensive utilization and treatment of agricultural waste, promote the green development of agriculture, and reduce agricultural surface source pollution.

Finally, the government should shift the focus of development to central cities. Given the substantial economic and environmental advancements in eastern cities after the reform and opening up, for cities in the midwest, the improvement of their subsequent development potential is relatively limited. Through the implementation of the heterogeneity analysis method, various development indicators have been analyzed in depth, and the influence of the central cities surpasses that of the eastern cities. The central cities are geographically connected with the western cities, and the economic development and social progress of the central cities, as the core power source, confirm their strong leading and promoting roles in the prosperity of the whole society. This has become a key factor in promoting the overall social progress in the region. For the government, relying on national strategic frameworks such as the Belt and Road Initiative can carefully build an efficient and coordinated development system for eastern and western urban agglomerations and promote the efficient operation and continuous upgrading of modern regional development mechanisms by optimizing the spatial layout and resource allocation strategies.

5.3. Limitations and Future Research

This research only takes China's waste-free city policy in 2018 and utilizes the primary cohort of pilot metropolitan areas as the background. On the one hand, there may be potential bias in the data due to the fact that the data for the second batch of pilot cities in 2022 could not be collected; on the other hand, the waste-free city policies in different countries have different mechanisms and paths in terms of economic development, environmental governance, and ecological construction. Hence, the construction benefits of the second batch of domestic waste-free cities have yet to be tested by other scholars.

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