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Study on the Impact of Carbon Emission Trading Pilot on Green Land Use Efficiency in Cities

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Abstract: Under the overarching principle of sustainability, the reliance solely on expanding the landmass to meet the demand for high-quality economic growth is unsustainable. To address the need for harmonious ecological–economic development, this paper examines the influence of carbon emissions trading (CET) policies on the urban land green utilization efficiency (LGUE) from an environmental regulation perspective. Harnessing municipal panel data from 278 cities across China between 2011 and 2020, the study initially employs a super-efficient SBM model to estimate the urban LGUE. Further, a progressive difference-in-differences methodology is utilized to delve into CET's impact on the LGUE. The main results are as follows. (1) Through the visual analysis of the time–space evolution trend, the LGUE displays pronounced spatial agglomeration, with the LGUE values being higher in the central and western regions compared to the east, and in the south versus the north. Over time, it follows a "U-shaped" change pattern. (2) The CET policy exerts a statistically significant positive influence on the LGUE, although this effect is accompanied by a temporal lag. Following a number of approaches to validate the results, the impact remains significant. (3) Regarding the heterogenous effects, the CET policy appears to have a greater impact on resource-based cities and those in the eastern part of China relative to non-resource-based and central–western cities. This research offers empirical evidence and countermeasure recommendations for the further refinement of the CET policy to enhance the urban LGUE.

Keywords: carbon emissions trading pilot; progressive double difference; land green use efficiency; super-efficient SBM model

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1. Introduction

Land serves as a crucial means of production for human beings and is also a basic condition for urban development. Over the past two decades, global cities have continued to expand at a rapid pace, with the global land area increasing from 239,900 square kilometers in 2000 to 519,800 square kilometers by 2022, an expansion of 117.49 per cent. According to the In the State of the World's Cities 2022 report and the Global Environment Outlook: Urban Edition report published by the United Nations, the global urbanization rate is expected to reach 68 per cent by 2050, and the proportion of the world's population that is urban will be close to 70 per cent. Urbanization has brought about the agglomeration of the population and industry, but, with urbanization, the expansion of urban built-up land is accelerating. Ecological land is gradually being squeezed out due to the poor use of reclaimed land. Finally, the urban land use efficiency (LUE) is low, and the economic and environmental benefits are unbalanced [1,2]. Moreover, the pattern of urban land use is gradually being commercialized and capitalized, and local governments are unable to provide funds for public green space in order to maximize the revenue from land leasing, which in turn results in the loss of public green space [3]. It has been discovered that the most promising method to enhance the LUE is to address the conflict between the demand for growing urban areas and the diminishing supply of land resources [4]. Thus, at present, the question of how to economize and efficiently and greenly utilize land resources has emerged as a paramount concern amidst the progression of human civilization [5].

The topic of LUE has attracted a great deal of academic attention, with scholars studying the impact of the urban LUE in terms of changes in the ecological and social environments [6]. Studies have also investigated the LUE's correlation with ecosystem health [7], its decoupling from carbon emissions [8], and the relationship with the socioeconomic progress of urban agglomerations [9]. In recent times, the proliferation of green ideologies has prompted several academics to propose the notion of water resource green efficiency, grounded in the principles of sustainable development [10,11], and green development is the inevitable choice in the economic development of all countries in the world and a crucial avenue to surmount the existing constraints of development. Therefore, research on LUE has gradually shifted in the direction of land green use efficiency (LGUE). Urban LUE represents a comprehensive evaluation of the optimal exploitation of various social and economic resources within a specific urban land context, encompassing the strategic integration of capital and labor resources to achieve maximum productivity gains [12]. Despite this, the traditional land development patterns are inefficient, leading to excessive pollutant emissions and compromising the quality of life of urban residents. Against this background, the urban LGUE has emerged. This metric gauges the extent to which green outputs are achieved by efficiently utilizing human resources, capital, and energy inputs, while concurrently minimizing environmental stressors [13]. It serves not only as an economic barometer but also a concrete manifestation of the realization of ecological and economic harmony. In contrast to conventional urban LUE metrics, which tend to prioritize economic returns, the urban LGUE embodies a harmonious fusion of economic, social, and environmental benefits, thereby fostering the long-term sustainability of urban land use practices.

Most current studies have explored the impact of relevant government policies on LGUE. For instance, studies have shown that the implementation of pollution permit trading systems can foster green technological innovation and industrial restructuring, thereby enhancing the LGUE [13]. The development of smart cities has also been found to boost the LGUE, as it spurs the growth of the information sector and the regional innovative capacity [14]. Furthermore, the establishment of China's Free Trade Zones has been positively linked to LGUE enhancements, exhibiting spatial spillover effects [15]. Moreover, with the help of ArcGIS and ESTDA technologies, some scholars have deeply explored the evolution characteristics of Chinese cities' LGUE in the spatiotemporal dimension [16]. Meanwhile, a large amount of literature focuses on the many influencing factors of LGUE, and some studies have revealed that collaborative innovation plays an important role in narrowing the differences in LGUE within city clusters [17]. Alternatively, some use the GTWR model to explore this, and studies have found that the LGUE is positively affected by economic structure adjustments [18], industrial structure upgrading [19], the urban morphology [20], regional economic integration, and other factors [21].

There are a number of measurement approaches for LGUE. Some studies have constructed a two-stage DEA model to assess it [22]. Moreover, in order to maximize the economic, social, and environmental utility in urban land use, some incorporate slack-based measures (SBM) to measure unwanted outputs [23]. In addition, other studies have used the super-efficiency DEA model and the Malmquist index to comprehensively assess the land eco-efficiency from both economic and ecological perspectives [24]. Some studies have even used the EBM model to measure the urban LGUE and discovered that the southeastern coast is more efficient than the northwestern inland provinces [25]. These different measurements provide diverse perspectives for a comprehensive understanding of LGUE. This paper intends to apply the concept of green development to the field of LUE measurement and form the LGUE.

With the gradual establishment and development of the global carbon market, the carbon emissions trading (CET) pilot policy is also being promoted and deepened. Against this backdrop, China is committed to building a more comprehensive and unified carbon emissions trading system to promote the sustainable development of a low-carbon economy. At present, studies on the impacts of the pilot CET policy are mainly conducted from three perspectives: economic, social, and environmental. In terms of economic benefits, a study found that the CET policy not only helps to promote industrial development, but also achieves economic growth while reducing carbon emissions, demonstrating a win–win effect [26]. However, it also raises incomes in China's rural areas [27], promotes foreign direct investment [28], drives the economy towards decarbonization [29], and promotes the transformation of the industrial structure [30,31]. The pilot CET policy was also found to reduce abatement costs and provide effective compensation for lost economic outputs [32,33]. In terms of social benefits, the CET policy has produced a certain employment dividend, which can expand the scale of employment [34], and its impact on employment has gradually increased [35]. Secondly, from an innovation perspective, certain academics contend that while the CET pilot policy encourages enterprise innovation and fosters positive impacts within the pilot region. It simultaneously exerts a notable restraining influence on adjacent areas [36,37]. Some scholars believe that CET inhibits green technological innovation [38]. Moreover, it was revealed that the "weak" Porter effect has yet to materialize within the present Chinese carbon trading market, indicating that the CET pilot has not triggered corporate innovation and has instead led to a decrease in the share of green patents [39]. In terms of environmental benefits, it is mainly researched from two perspectives: carbon emissions and air pollution. A large amount of literature proves that CET has obvious carbon emission reduction effects [40–42], and the effects are enhanced over time [43]. Some research has revealed that the principal avenue by which to achieve emission reduction effects involves reducing the output of the industrial economy, especially in the developed eastern region, where the control effect is better [44]. However, there are also opposing findings. Surprisingly, one study revealed that the enactment of the CET policy resulted in a notable surge in carbon emissions within the designated pilot cities [45]. Secondly, in terms of air pollution control, the CET policy significantly improved the environmental quality [46,47] and reduced the concentration of PM2.5 [48], and some research has also discovered that the CET policy has reduced SO_2 and NO_x emissions [49].

In summary, there is a significant amount of literature pertaining to the CET policy, yet its impact on the urban LGUE remains unexplored. Utilizing panel data from 278 prefecture-level cities in China from 2011 to 2020, this study integrates the CET policy and urban LGUE within a unified framework. Employing a gradual double-difference method, we empirically investigate its influence, aiming to provide policy insights for the enhancement of China's LGUE and optimization of government priorities. Compared to the extant literature, this study innovatively integrates the "green" development philosophy with the urban LUE, refining the construction of the LGUE indicator. Utilizing the super-efficiency SBM model, we accurately quantify the LGUE and thoroughly analyze its spatial development patterns, providing clear guidance for the optimization of the national land use structures and fostering high-quality growth. Additionally, our research treats the CET policy as a natural experimental subject, rigorously examining the heterogeneous impacts of pilot initiatives, which holds profound theoretical significance and practical implications in terms of comprehensively elevating China's LGUE, promoting socioeconomic advancement, and nurturing ecological civilization. Simultaneously, the findings of this study offer a valuable reference for emerging nations and developing countries in formulating relevant policies.

The subsequent sections of this paper are organized as follows. Section 2 introduces the research's theoretical analysis against the background of the conception and execution of CET policies. Section 3 introduces the asymptotic double-difference model, the measurement of the urban LGUE indicator, and its spatial changes. In preparation for the empirical analysis in Section 4, we present the origins of our data and accompanying descriptive statistical measures. Section 4 unveils the empirical regression outcomes and corresponding analyses, elucidating the influence of CET pilot measures on LGUE. Section 5 discusses the policy implications, and also explores the limitations encountered in the course of our research. Section 6 offers conclusions.

2. Policy Background and Theoretical Analysis

2.1. Policy Background

With rapid economic growth, environmental pollution is increasing, and greenhouse gas emissions are growing substantially, bringing many negative impacts on food security, socioeconomic development, and land health, posing a global challenge [50]. CET creates a demand for emissions reductions by humanity as a whole in order to avert the inevitable climate catastrophe. In 1986, the concept of CET was initially introduced by the American economist Dale. The theoretical basis of CET is to give scarcity attributes to carbon emissions through total control, thus reducing the overall marginal abatement cost, improving the abatement efficiency, and maximizing overall welfare. Owing to the exclusivity and non-competitiveness inherent in carbon emissions, Coase put forward the concept of "transaction costs" in "The Problem of Social Costs" in 1960 and put forward the solution to the problem of "externality" from the perspective of the relationship between property rights and transaction costs, laying the theoretical groundwork for the adoption of the CET policy [51]. CET is a means of pollution control based on the Coase Theorem, based on the clear definition of property rights, treating carbon emissions as a commodity to be bought and sold and adopting the market mechanism for management. At the present time, CET serves as a crucial economic instrument used by the international community and various countries in exploring solutions to the global climate problem and in controlling carbon emissions. Most countries see CET as an environmental economic policy, through the management of carbon emissions overall, utilizing market mechanisms to provide incentives for enterprises to mitigate their carbon emissions and subsequently reduce the overall carbon footprint through the regulation of carbon emission rights pricing, thus ultimately avoiding the climate crisis.

According to the 2022 World Bank Country Climate and Development Report for China, China contributes approximately 27 percent of the worldwide carbon dioxide emissions, comprising one third of the total greenhouse gas emissions globally. Rapid economic development is often accompanied by environmental pollution and the emission of large quantities of greenhouse gases. CET, arising from climate negotiations, serves as a means to mitigate energy consumption and minimize damage to environmental health [52]. To attain the objective of "carbon neutrality", the Chinese National Development and Reform Commission issued the "Notice on Carbon Emission Trading Pilot Work" (hereinafter referred to as the "Notice") in October 2011. The Notice emphasizes the utilization of market mechanisms to efficiently achieve the 2020 action target of reducing greenhouse gas emissions while minimizing costs. It further underscores the need to expedite the transformation of economic development patterns and the advancement of industrial structural upgrading. The pilot CET policy is one of the most representative market-oriented low-carbon policies in China. The first batch of carbon emissions trading pilot policy implementation was in 2013, with pilot provinces and municipalities in Guangdong Province (Shenzhen), Shanghai, Beijing, and Tianjin; the second batch was in 2014, with Hubei Province and Chongqing Municipality joining the pilot provinces and municipalities; and the third batch was in 2016, with Fujian Province following suit. China's CET system was already fully operational in 2021. It is already the world's largest carbon trading market, three times that of the European Union, covering annual carbon dioxide emissions of about 5.1 billion tons. The pilot CET policy implemented in China is a significant policy tool to incentivize carbon emission units to take measures to reduce their carbon emissions and ensure appropriate supervision and management, to promote synergies in reducing pollution and carbon emissions, and to positively address climate change. Regarding the three batches of pilots, the first phase was mainly based on economically developed provinces and cities, and it was then slowly extended to other provinces and municipalities. Using the ArcGIS software version 10.6, the pilot policy implementation areas were mapped, as in Figure 1.

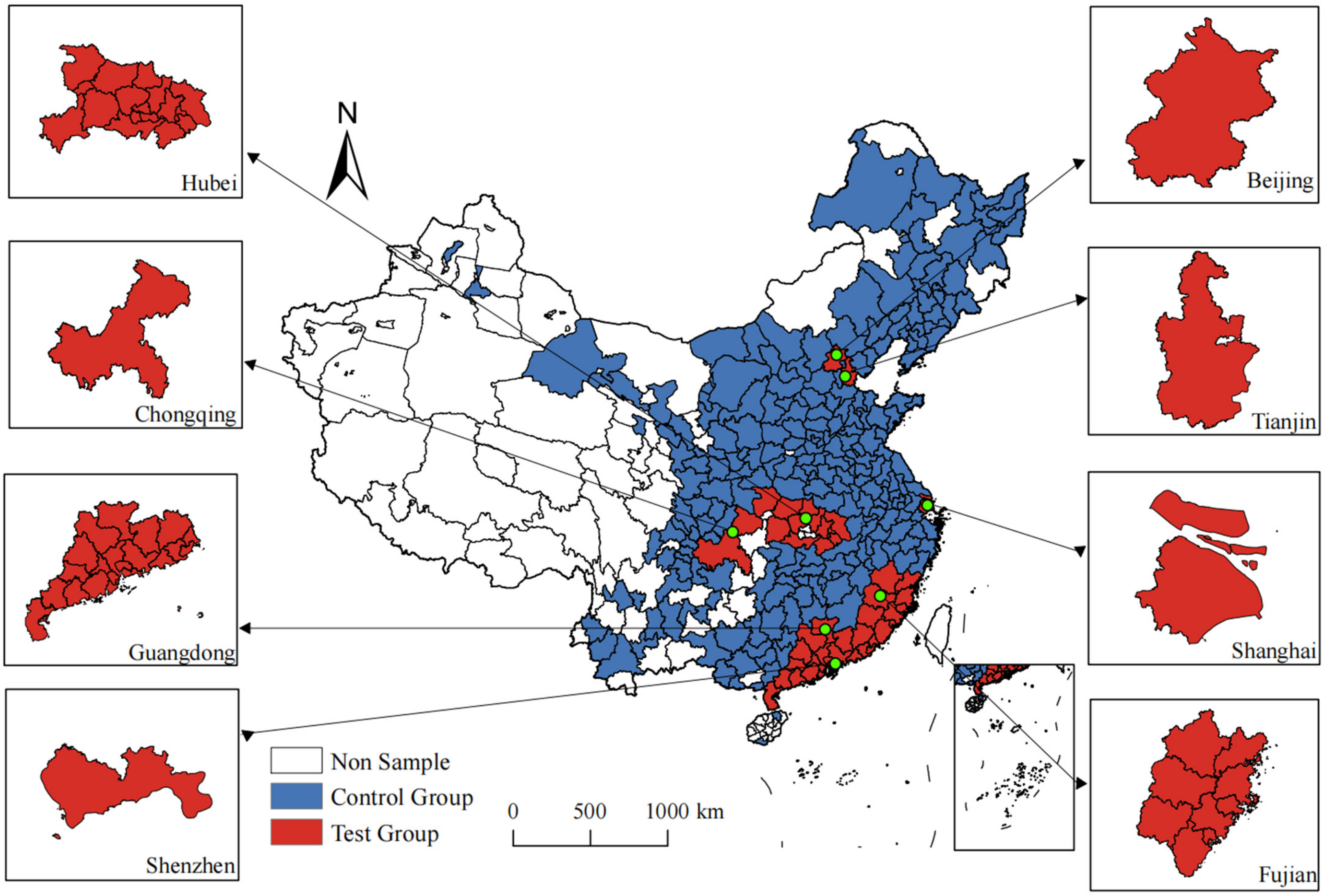

Figure 1. Carbon trading pilot policy implementation areas.

2.2. Theoretical Analysis

CET pilot policies involve land management and utilization at multiple levels. CET pilot policies include the carbon emissions and carbon sinks of land resources (such as afforestation, forest protection, soil carbon sequestration, etc.) in a CET market system, and these activities that affect carbon emissions and absorption will be the objects of accounting, monitoring, and trading. CET policies can influence the LGUE in three ways: cost-forcing effects, financial support effects, and social effects.

The cost-forcing effect. The price of carbon emission allowances, functioning as a market signal under the CET regime, effectively establishes a green benchmark for energy-intensive, high-emission ventures. The green threshold imposed by the CET policy curtails the flow of capital to highly polluting and energy-consuming entities, constraining the growth of established, high-carbon emitters while compelling firms to divest from inefficient, outdated production processes. It guides capital to the low-carbon and green technological innovation aspects, ultimately optimizing resource distribution and enhancing their productive application [53]. Moreover, part of the enterprise's capital needs to be used to purchase carbon emission rights, and the CET policy creates a limited number of tradable emission allowances, i.e., a cap, to be distributed among participants in the economy [54]. There are also financial penalties if a company fails to meet its quota clearance obligations on time, and, in severe cases, the company's operations can be halted. Carbon trading has led to a 25% contraction in the availability of land for energy-intensive sectors, and, due to the increased cost of carbon emissions, the requirements for the industrial use of land will be reduced after the implementation of the policy, promoting green development [55]. Therefore, CET policy can realize the efficient use of regional resources through the cost-forcing effect. From the perspective of land use, production activities attached to the land in the output capacity and pollution reduction adjustments will also have a significant role in promoting LGUE.

The financial support effect. The CET mechanism follows the "principle of total control", and enterprises can obtain quotas in accordance with the provisions of the regulations. If, in the process of enterprises' implementation of emission reduction measures, there are still surplus quotas, the enterprises can sell their unused carbon emission quotas in the trading market to obtain income. CET policy can provide diversified financing channels through the market mechanism, reduce energy use, control the level of pollutant emissions, and guide enterprises to direct the flow of funds and resources to the more efficient green energy sector [48]. Increasing the production efficiency generates favorable incentives to raise the standard of land use, realize a win–win situation between the financial and ecological advantages in land use, and enhance the level of excellence of the economy of the area.

The social effects. CET policy can reshape producer behavior and consumer demands, increase people's awareness of climate change, and guide social participation in environmental monitoring and pollution control, including spontaneous participation in carbon emissions trading and the supervision and management of corporate emissions behavior. This will encourage residents to practice green and low-carbon consumption; minimize the use of resources, the release of pollutants into the environment, and the generation of greenhouse gases during the consumption process; and promote LGUE [55]. For example, Beijing, as one of China's pilot cities for CET, is not only a city where enterprises can participate in the carbon emissions trading system; it also mobilizes citizens to participate in emissions reduction, and citizens can use public transport to obtain carbon credits and participate in trading activities in the carbon market.

H1. *CET pilots help to improve the urban LGUE.*

3. Model Setting and Variable Selection

3.1. Benchmark Regression Modeling

In this study, the promulgation of the CET pilot policy is regarded as a "quasi-natural experiment". Due to the fact that the CET pilot policy was implemented in batches in eight Chinese provinces and cities between 2013 and 2016, and because the processing times of the policies varied sequentially across batches, making it impossible to form a uniform control group using the traditional method, we adopt the progressive double-difference method to set the policy experimental group in batches. This can better assess whether the exogenous shock of a certain city being classified as a CET pilot improves the urban LGUE. The model is set up as follows:

$$LGUE_{it} = \alpha_0 + \alpha_1 DID_{it} + \alpha_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

$LGUE_{it}$ denotes the land green utilization efficiency of city i in year t; DID_{it} is the policy treatment group, which is used to characterize whether city i has implemented the CET pilot policy in year t. Its coefficient α_1 reflects the overall effect of the CET pilot policy on the urban LGUE. If α_1 is significantly greater than 0, it means that, before and after policy implementation, the LGUE of the pilot cities is significantly higher than that of non-pilot cities, i.e., it verifies the research hypothesis of this study. X_{it} is a set of control variables set up at the city level, controlling the potential influence of other factors on the urban LGUE, and α_2 is its coefficient. α_0 is a constant term, the area fixed impact is represented by μ_i and the time fixed impact by λ_t, and the term for random errors is represented by ε_{it}.

3.2. Variable Selection and Data Description

3.2.1. Dependent Variable

Drawing on the method of Tone (2003) [56], we construct a non-radial, non-angular super-SBM model and use the MATLABR2022a software to calculate the LGUE in the variable compensation of scale (BCC) scenario. The super-SBM model overcomes the problem whereby multiple DMUs may exhibit an efficiency score of unity in the traditional SBM model, so that the efficiency difference of each decision-making unit can be effectively differentiated and the results are more accurate. When measuring the LGUE, the non-desired output of environmental pollution is considered, and the non-desired output needs to be included in the model [57]. For this reason, the super-efficient SBM model, which is non-radial and non-angular with non-desired outputs, is chosen to measure the LGUE.

The indicator of the urban LGUE is the ability of the production factors, such as capital and labor, invested in the process of urban land use to be transformed into economic, environmental, and other output benefits under the conditions of a certain level of technology. The difference between this and the traditional LUE is that it places more emphasis on the environmental outputs of the land use activities, presenting the remarkable characteristics of high efficiency and greenness [13]. Drawing upon the definition of the urban LGUE considered in this paper, we proceed to identify the pertinent indicators from the tripartite perspective of inputs, outputs, and undesirable outputs, thereby substantiating the construct of urban LGUE, as shown in Table 1.

Table 1. Evaluation system of urban LGUE.

Index	Specific Index	Measurement Method	Unit
Input	Labor	Number of employees at year-end	10,000 persons
	Capital	Urban fixed asset investment	10,000 CNY
	Land	Urban built-up area	km^2
Output	Expected outputs	GDP (measured as real GDP at constant 2000 provincial prices)	10,000 CNY
		Urban green space area	km^2
	Non-expected outputs	Industrial wastewater emissions	10,000 tons
		Industrial SO_2 emissions	tons
		Industrial fume and dust emissions	tons
		City CO_2 emissions	10,000 tons

(1) Input: labor, capital, and land are selected, employing the year-end number of employees per unit as a proxy for labor input. City fixed asset investment serves to denote capital infusion, while the area of urban construction land aptly signifies the terrestrial resources committed [58]. (2) Expected outputs: among the desired outputs, both economic and environmental benefits are considered; gross domestic production (GDP) indicates economic outputs, and environmental aspects are expressed in terms of the urban greening area. (3) Non-expected outputs: taking into account the environmental pollution and carbon emission constraints [8] and selecting environmental pollutants stemming from land usage as the primary focus, we choose urban industrial wastewater discharge, industrial sulfur dioxide emissions, and industrial particulate matter release as representative indicators. City-level carbon emissions encompass both direct emissions stemming from energy consumption, such as those generated by gas and liquefied petroleum gas, and indirect emissions resulting from electricity usage, transportation, and thermal energy consumption. These emissions are summed to yield the total carbon footprint for each respective city [59]. Direct energy-related carbon emissions are calculated utilizing the conversion factors provided by the IPCC's 2006 guidelines [60]. To determine the carbon emissions emanating from electricity consumption, we employ regional grid baseline emission factors in conjunction with the city's electricity consumption data [61]. Energy consumption and carbon emissions from urban transport are calculated following the approach of Li et al. [62]. With regard to urban thermal energy, primarily derived from boiler room heating and heat power plant supply, the IPCC's 2006 guidelines stipulate a carbon emission coefficient of 2.53 kg CO_2/kg for every kilogram of raw coal. Thus, the carbon emissions generated by centralized heating can be precisely quantified by applying this factor to the volume of raw coal consumed for thermal energy purposes [59]. This paper emphasizes the inputs and outputs of the urban LGUE, which is in line with Liu's considerations [63]; the difference is that this work adds the urban greening area in the desired output. The greening coverage

area can roughly reflect the ecological impacts of land use in the construction of the city, as well as the ecological status of the city, so the output can be considered a "green" indicator.

3.2.2. Independent Variable

Within this study, the CET pilot initiative is conceptualized as a quasi-natural experiment, with the interaction term (DID) between the policy implementation time dummy and the pilot region dummy serving as the central explanatory variable. If a city is classified as a CET pilot area, the area dummy variable is taken to be 1 to represent the treatment group; otherwise, it is 0 to represent the control group. At the same time, the time dummy variable assumes the values of 0 and 1 prior to and following the policy's enactment. Therefore, the DID coefficient reflects the net influence of the CET pilot affecting the urban LGUE. The CET pilot policy has undergone multiple iterations, necessitating the rigorous selection of experimental cohorts to ensure scientific validity. As such, this paper includes provinces and cities subjected to the CET pilot policy across several phases (Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong Province (Shenzhen City), and Fujian). The time of the implementation of the CET pilot policy was 2013, 2014, and 2016, respectively.

3.2.3. Control Variables

This paper consolidates the extant scholarship to account for salient variables impacting the urban LGUE [15]. These variables include (1) the per capita GDP (RGDP), as an increase in the level of economic development is often accompanied by an increase in the LGUE [9], and cities boasting elevated levels of economic prosperity are able to invest more funds and policies in areas such as technological innovation, land planning, and environmental governance, which can positively affect the efficiency of green land use. Simultaneously, heightened developmental tiers could lead to escalated industrial activity, transport demands, and energy consumption, which could potentially impede advancements in LGUE. (2) The level of financial development (FIN) utilizes the year-end loan balances relative to the GDP as an indicator of financial development, and an escalation in financial development levels might facilitate corporate investment in high-emission sectors and high-pollution projects, which is not conducive to LGUE [64,65]. (3) The degree of government intervention (GOV) is expressed in terms of local government expenditure as a proportion of the GDP; an increase in local fiscal expenditure means that financial subsidies and investments related to land investment will be relatively higher, thus increasing the LGUE; on the other hand, urban land use planning is orchestrated by the governing body, and a modicum of administrative involvement is beneficial to enhance the urban LGUE [20]. (4) The urbanization rate (UR) is reflected via the ratio of the urban to total population. The advancement of urbanization is usually accompanied by an increase in urban expansion and land development; with urban expansion, the re-planning of the urban layout can result in the more appropriate utilization of space and further optimization of the land use pattern. When considering the development of a new type of urbanization, this can be accomplished by reinforcing technology and adjusting environmental management policies, which will also contribute to enhancing the intensive land utilization and land ecological benefits, further contributing to the LGUE [11]. On the other hand, the advancement of urbanization may also result in limited agricultural labor resources in urbanized areas, leading to an increase in the application of fertilizers and other inputs, resulting in environmental pollution and a reduction in LGUE [66]. (5) The stringency of environmental regulation (ER) is operationalized as the SO2 removal rate, industrial smoke (dust) abatement rate, and industrial solid waste comprehensive utilization rate. These parameters are synthesized through the entropy method to compute the ER intensity. Environmental regulation prompts enterprises to protect the environment, increases the cost of emissions per unit land area of the enterprise, and forces the enterprise to reduce its exploitation of the land and pollution of the surrounding environment so as to improve the LGUE [67,68].

3.2.4. Data Source

As a developing nation boasting the largest populace and territorial extent globally, the exploration of LGUE within Chinese cities holds immense significance. Delving deeper into the LGUE of these urban centers will not merely enhance China's urbanization efforts but also offer crucial insights and instructive examples for other developing nations. The CET pilot policy was implemented in batches in 2013, 2014, and 2016, and, in order to better assess the CET policy's effects, this paper focuses on the time period of the first two years of the earliest batch of pilot implementation, namely 2011, and the last four years of the last batch of pilot implementation, namely 2020. Regarding the study area, the pilot areas include municipalities and provinces, and this paper focuses on the prefecture-level city, taking 278 prefecture-level cities in China as the study sample. The study area excludes the Tibet Autonomous Region, Hong Kong, Macao, and Taiwan due to data limitations. Data are obtained from the National Bureau of Statistics of China (2012–2021) (https://data.stats.gov.cn, accessed on 20 June 2023), China Energy Statistics Yearbook (2012–2021), China Urban Statistical Yearbook (2012–2021), and China Urban Construction Statistical Yearbook (2012–2021). Land use data are from the China Land Administration Department (2012–2021), China Statistical Yearbook for the Sciences and Technologies, and China Statistical Yearbook for Trade and Foreign Economy. Some of the missing data are obtained from local statistical yearbooks, government gazettes, etc., and the missing data are replaced by interpolation. See Table 2 for the descriptive statistics of each variable. The number of sample observations is 2780.

Table 2. Descriptive statistics.

	Variable	Obs	Mean	Std. Dev.	Min	Max
Dependent variable	LGUE	2780	0.31	0.15	0.14	0.72
Independent variable	CET	2780	0.12	0.32	0.00	1.00
Control variables	RGDP	2780	40,500.00	30,800.00	99.00	468,000.00
	FIN	2780	1.58	0.59	0.16	16.73
	GOV	2780	0.20	0.10	0.04	1.16
	UR	2780	82.02	21.49	0.24	418.96
	ER	2780	0.46	0.22	0.07	1.54

4. Results

4.1. Spatial Distribution of LGUE in Chinese Cities

To delve deeper into the spatial distribution of the urban LGUE, we selected four years, namely 2011, 2014, 2017, and 2020, and examined the geographical dispersion of the urban LGUE across China, as illustrated in Figure 2. Considering the temporal evolution traits of the urban LGUE from 2011 to 2020, the LGUE of Chinese cities shows a "U" type of change characteristic. This could stem from the enforcement of the "Twelfth Five-Year Plan" and "Thirteenth Five-Year Plan", aimed at expeditiously boosting the economic efficiency. As the ecological environment is deteriorating, the public has gradually realized that the high-energy, high-emission production mode will cause the pollution of the environment, which will result in a sustained downturn in LGUE and a deviation from the current economic development trend. Thus, the production mode will be changed from the rough type in the beginning to an intensive one, and the emphasis will be placed on environmental protection.

In examining the characteristics of the spatial distribution of the urban LGUE from 2011 to 2020, there are significant differences in LGUE between cities, and the spatial clustering of the LGUE is obvious. The LGUE in the central and western parts of the country is higher than that in the eastern part of the country, and the LGUE in the southern sector surpasses that of its northern counterparts, which is similar to the results obtained from previous research [63,69]. Firstly, the LGUE is generally lower in the eastern cities, which could be linked to their economic development levels. Most of the workers tend to travel to the coastal cities with higher salaries and wages to look for jobs, which leads to the limited land area in the eastern cities being overly used for the construction of residential housing. Meanwhile, in the western cities, which are more extensive and have greater natural resources or vegetation cover than the eastern cities, more land can be used for green construction. The LGUE also surpasses that of eastern municipalities. The LGUE of the southern cities is higher than that of the northern cities, probably because most of the northern cities are developed with heavy industry, and, due to the climate, the northern cities need to be heated in the cold winter, consequently rendering the environmental pollution in the north more pronounced than in the south. Thus, the LGUE is lower than that of the southern cities.

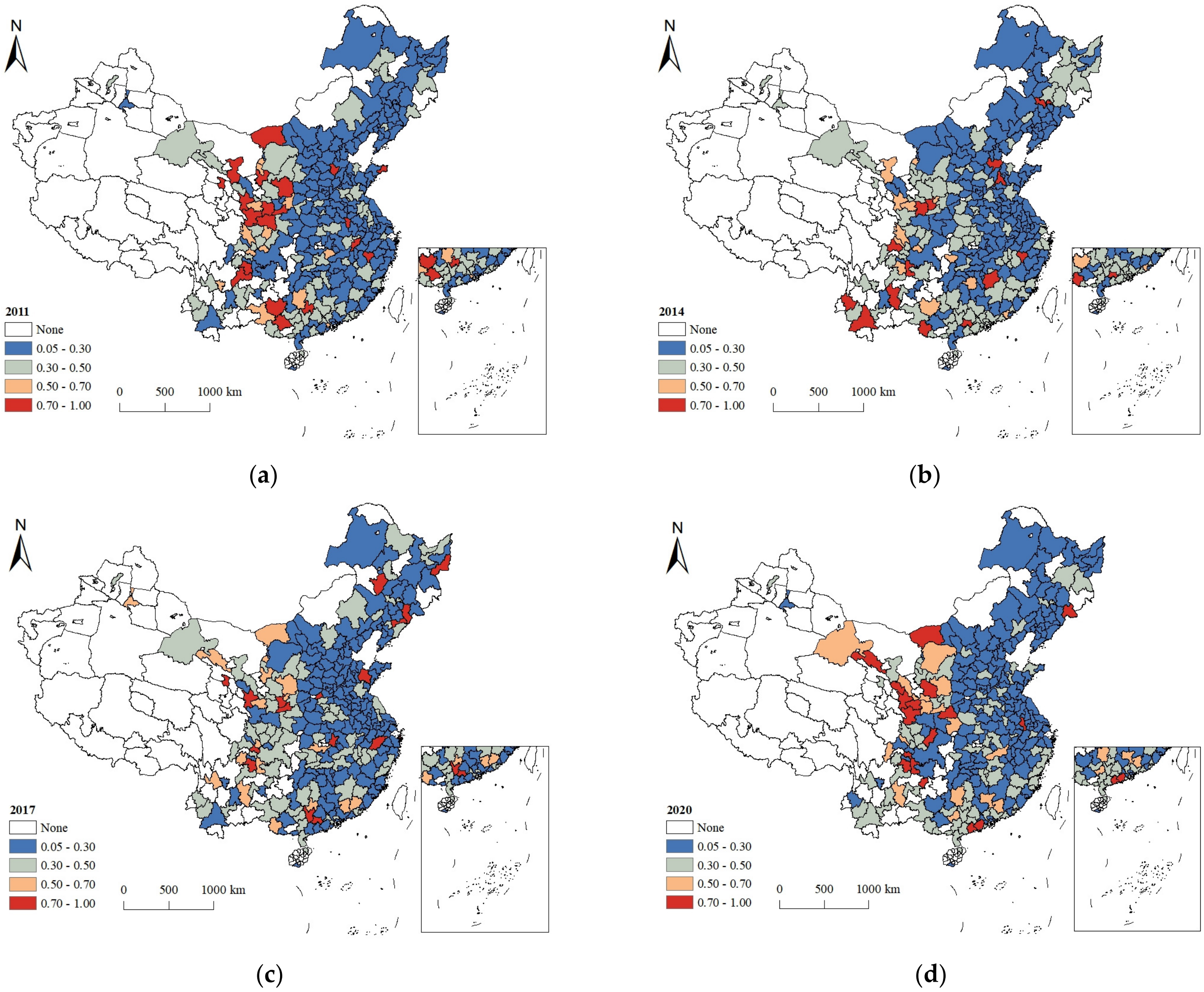

Figure 2. (**a**) Spatial distribution of LGUE in Chinese cities in 2011; (**b**) spatial distribution of LGUE in Chinese cities in 2014; (**c**) spatial distribution of LGUE in Chinese cities in 2017; (**d**) spatial distribution of LGUE in Chinese cities in 2020.

4.2. Benchmark Regression

Based on the previous model design, an asymptotic double-difference model is used to estimate Equation (1) and the benchmark regression outcomes are presented in Table 3. In Table 3, column (1) reveals that the regression coefficient of the policy variable DID without adding control variables is 0.0337, satisfactorily passing the significance test at the 1% threshold. Column (2) illustrates the outcome upon incorporating control variables and adjusting for area-specific fixed effects, but excluding temporal fixed effects. It is evident that the regression coefficient of the policy variable DID is 0.0270, displaying statistical significance at the 5% level, manifesting a markedly positive association. Finally, column

(3) is the predicted coefficient of the rule's variable DID after adding both control variables and time-area two-way fixed effects. It shows that the policy variable DID has a regression coefficient of 0.0319, which is significantly positive at the 5 percent level, and, specifically, the implementation of CET increases the urban land use efficiency by about 3.19 percent. The final result shows that the policy variable DID is strongly positive at least at the 5% level, regardless of whether the effects of other factors are considered, and that CET implementation promotes sustainable urban land use and improves the LGUE. This estimation supports Hypothesis 1. This conclusion parallels the findings of prior inquiries indicating that CET improves the environmental impact of LGUE in pilot areas [70]. Moreover, Zhang's research investigates the intricate, non-linear impacts of environmental regulation on LUE, emphasizing that both formal and informal environmental controls contribute positively to enhancing the urban LUE [71]. CET policy, notably, is a market-driven environmental regulation. Expanding upon this, our study conducts an in-depth evaluation of the precise implications of the CET environmental regulation on the urban LGUE. The outcomes of this research can offer valuable policy lessons and guidelines that serve as a global reference, enabling diverse countries and regions worldwide to optimize their land distribution practices and LGUE effectively.

Table 3. Benchmark regression results of CET policy on LGUE.

	(1)	**(2)**	**(3)**
	LGUE	**LGUE**	**LGUE**
DID	0.0337 ***	0.0270 **	0.0319 **
	(2.618)	(2.232)	(2.465)
Constant	0.3109 ***	0.3071 ***	0.3120 ***
	(117.557)	(11.178)	(10.581)
Observations	2780	2780	2780
R2	0.433	0.434	0.435
Controls	NO	YES	YES
Regional fixed effect	YES	YES	YES
Time fixed effect	YES	NO	YES

Note: Standard errors of regression coefficients are in parentheses. **, and *** indicate significance levels of 5%, and 1%, respectively.

4.3. Parallel Trend Test

Is the difference in urban LGUE before and after the CET pilot necessarily due to the pilot policy itself, or is it the effect of other factors that are difficult to observe? This test is a necessary element when applying the double-difference method. In the relevant characteristics of the experiment, if the control groups contravene the parallel trend supposition preceding policy introduction, direct regression would lead to the biased estimation of the policy impact. In this paper, we adopt the incident-based research method to carry out the examination, which can not only test for an increase or decrease in the dependent variable in both the experimental and control cohorts prior to policy implementation, but can also shed light on the policy's temporal dynamics post-implementation. We follow Jacobson et al.'s method of using event analysis to conduct parallel trend tests [72], and we establish the following experimental model:

$$LGUE_{it} = \beta_0 + \sum_{n=-3}^{6} \beta_n DID_{it}^{n} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{2}$$

DID^n is a relative annual policy variable derived in relation to the pilot implementation annum. DID^n takes the value of 1 for cities classified as pilots and 0 otherwise; where β reflects the policy pilot's temporal influence on the LGUE. This study examines the change from 3 years before the policy's implementation to 6 years after, i.e., from 2011 to 2020; the connotations of the residual variables align with those in Model (1).

Figure 3 illustrates the outcomes of the pre-treatment trend event study for the three periods before and six periods after the event. Before the occurrence of the pilot policy, the urban LGUE demonstrates no statistically significant divergence between pilot and non-pilot locales, thereby fulfilling the parallel trend assumption. Meanwhile, post-CET pilot policy implementation, the policy's positive effect materializes progressively. However, during the nascent stages, in the fledgling carbon trading market, the transaction is carried out intermittently, and the volatility of the transaction volume is large. During the third year, the policy's influence wanes, probably because the initial policy is still not perfect. There are a series of problems, such as the inaccurate allocation of quotas and inefficient operation of the market, so the policy's effect on the LGUE is not immediately apparent. However, after several years of implementation, the policy's effectiveness escalates, albeit with an observable lagged impact on the urban LGUE.

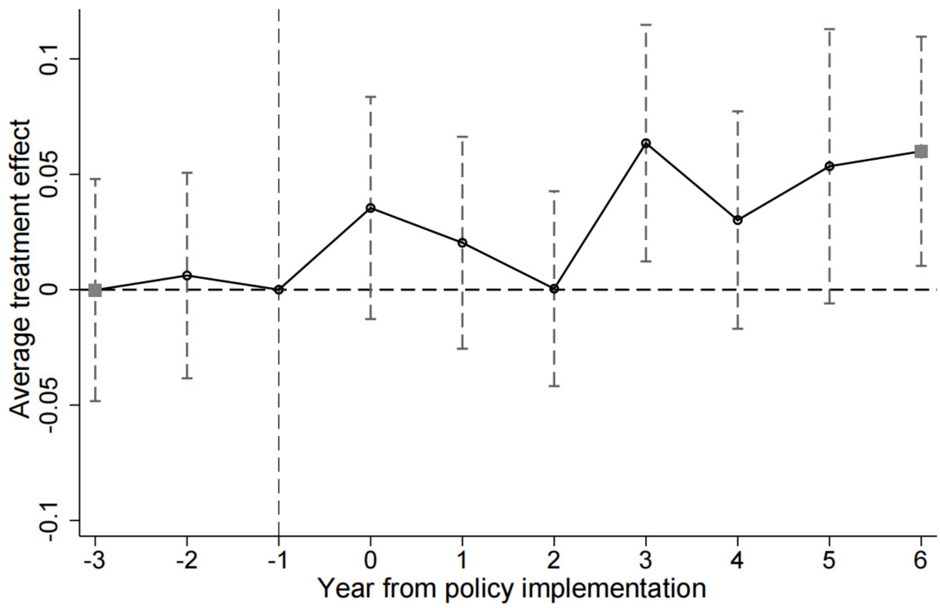

Figure 3. Parallel trend test.

4.4. Heterogeneity Treatment Effect Test

Based on the robust estimator devised by de Chaisemartin and D'Haultfoeuille to deal with heterogeneous treatment effects, this research detects potential heterogeneous treatment effects inside the baseline regression framework [73,74]. The treatment group is composed of those whose policy treatment status changes both before and after the policy enters into effect; the control group is composed of those whose status stays the same. The treatment effect is obtained by contrasting the outcomes of the individuals in the treatment group, who actually receive the treatment, with their counterfactual outcomes, which, after weighted averaging, provides an unbiased evaluation of the policy's switching effect. As in Figure 4, the event study graphs of the CET pilot in the first three periods and the last six periods are obtained, and the dynamic switching effect in each period can be clearly seen. The grey areas represent 95% confidence intervals, and the solid portion of the line indicates the average policy treatment effect. The policy effect is not clearly displayed prior to the execution of the CET pilot, but, following the opening of the CET market, the policy effect gradually appears. The above results are essentially consistent with the positive and negative trends of the treatment effects in the baseline regression, thereby implying that the benchmark regression passes the heterogeneous treatment effect test.

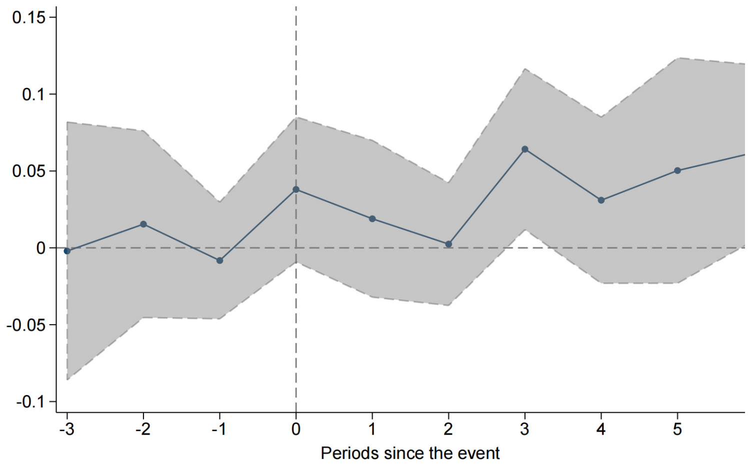

Figure 4. Heterogeneity treatment effect test results.

4.5. Robustness Tests

4.5.1. Removing Other Policy Distractions

To mitigate the potential influence of concomitant pilot programs on the regression outputs, this study incorporates both the NEDC and PAEC initiatives within the baseline model, subsequently re-evaluating said model. The estimation outcomes are presented in Table 4. Column (1) shows the regression results after incorporating the NEDC pilot policy. It can be seen that the CET policy remarkably contributes to the improvement of the urban LGUE. Column (2) shows the inclusion of the PAEC; the CET policy still significantly promotes the improvement of the urban LGUE, with a promotion coefficient of 0.027, and the regression coefficient of the CET policy has increased compared with that in column (1) of Table 4. In column (3), with the inclusion of the pilot policy of NEDC and the policy of PAEC, the CET policy still significantly promotes the improvement of the urban LGUE.

Table 4. Robustness results.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
	UGE	**UGE**	**UGE**	**UGE**	**UGE**
DID	0.0267 **	0.0270 **	0.0267 **	0.0309 **	0.0348 **
	(2.157)	(2.219)	(2.151)	(2.11)	(2.49)
NEDC	0.0022		0.0024		
	(0.143)		(0.151)		
PAEC		−0.0008	−0.0010		
		(−0.080)	(−0.099)		
Constant	0.3066 ***	0.3072 ***	0.3067 ***	0.2991 ***	0.3200 ***
	(11.100)	(11.187)	(11.111)	(9.57)	(10.81)
Observations	2780	2780	2780	2502	2720
R2	0.434	0.434	0.434	0.442	0.437
Controls	YES	YES	YES	YES	YES
Regional fixed effect	YES	YES	YES	YES	YES
Time fixed effect	YES	YES	YES	YES	YES

Note: Standard errors of regression coefficients are in parentheses. **, and *** indicate significance levels of 5%, and 1%, respectively.

4.5.2. Control Variables Lagged by One Period

To mitigate potential endogeneity and clustering problems (Moulton problem), all control variables are lagged by a single period. The estimation outcomes are depicted in column (4) of Table 4, where the coefficient of the policy variable DID remains significantly positive and withstands the 5% significance test. Thus, the baseline regression outcomes are verified as robust.

4.5.3. Removing Special Samples

Compared to ordinary prefecture-level cities, the six sample cities of Beijing, Shanghai, Chongqing, Tianjin, Guangzhou, and Shenzhen are excluded from the robustness test again, considering that municipalities belong to provincial administrative units and have higher economic autonomy than ordinary prefecture-level cities, which could affect the comparability of the samples and affect the regression outcomes [75]. The regression results are presented in column (5) of Table 4. It becomes apparent that the estimated coefficients of the policy variable DID remain affirmative and withstand the 5% significance test, even upon the exclusion of municipality samples, and the effect of CET implementation on the enhancement of the LGUE is still significant.

4.5.4. Placebo Test for Time plus Space

An important fundamental precondition for the double-difference methodology is the parallel trend assumption. However, the parallel trend assumption is inherently untestable because the treatment effect is mixed with the time effect after treatment. It is further examined whether there are confounding events that have been missed, and the possible biases that result. In this paper, the LGUE is validated using a mixed placebo test in time and space. In the mixed placebo test, a number of individuals are randomly selected as the "pseudo-treatment group" from the sample, and a uniform "pseudo-treatment time" is randomly selected for DID estimation to obtain an estimate of the placebo effect. This process is iterated 500 times to derive the distribution of the placebo effects.

The results of the spatiotemporal mixed placebo test show that the p-values for both the bilateral and the right-hand side are less than 10%, so that the average treatment effect remains significantly affirmative and withstands at the 10% level. More intuitively, the distribution of specific coefficient kernel densities and corresponding p-values can be seen from the distribution of the placebo effects in Figure 5, where the LGUE treatment effect estimate (dotted line in the figure) is located in the right tail of the distribution of the placebo effect, at the extremes. Specifically, the area of the left tail of this distribution greater than 0.032 is the left p-value of 0.982 (i.e., the probability that the placebo response surpasses the magnitude of the estimated treatment effect), the area of the right side greater than -0.032 is the right p-value of 0.018 (i.e., the probability that the placebo effect is less than the treatment effect estimate), and the probability that the absolute magnitude of the placebo response exceeds the treatment effect estimate is the bilateral value of 0.056, thus demonstrating that the baseline regression results remain robust.

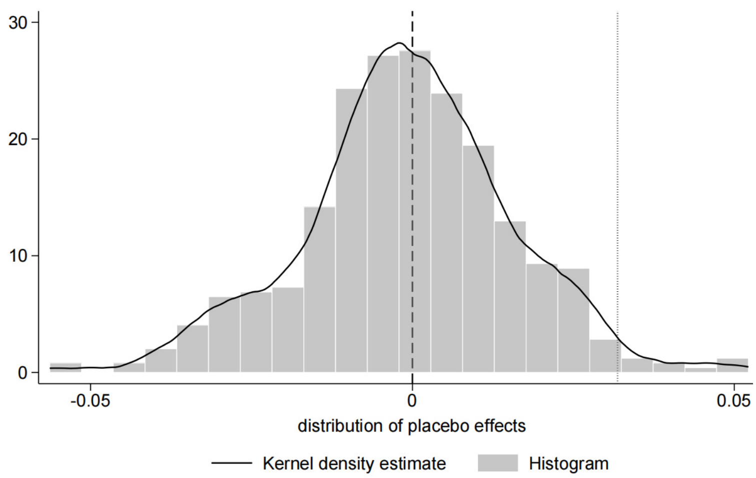

Figure 5. Placebo test for time plus space.

4.6. Heterogeneity Analysis

Different cities exhibit marked disparities in their economic development levels, resource endowment, marketisation levels, and land use. Accordingly, we categorize the cities based on their diverse attributes, the heterogeneity of the impact of CET policies on LGUE in different cities is further examined, and the regression results are compared; the outcomes of this analysis are presented in Table 5.

Table 5. Heterogeneity analysis results.

	(1)	(2)	(3)	(4)	(5)
	RC	**NRC**	**Eastern**	**Central**	**Western**
DID	0.0654 *	0.0277 *	0.0284 *	0.0217	0.0111
	(1.933)	(1.915)	(1.706)	(0.865)	(0.293)
Constant	0.2815 ***	0.3343 ***	0.2839 ***	0.2776 ***	0.3705 ***
	(6.203)	(8.299)	(3.745)	(7.055)	(5.319)
Observations	1140	1640	1000	990	790
R2	0.482	0.408	0.255	0.177	0.420
Controls	YES	YES	YES	YES	YES
Regional fixed effect	YES	YES	YES	YES	YES
Time fixed effect	YES	YES	YES	YES	YES

Note: Standard errors of regression coefficients are in parentheses. *, and *** indicate significance levels of 10%, and 1%, respectively.

At the outset, the heterogeneity of the impact of CET policies on the urban LGUE with differences in resource endowment is examined, and the sample cities are categorized according to the National Sustainable Development Plan for Resource Cities (2013–2020), as promulgated by China's State Council. Regressions are carried out on 114 resource cities (RC) and 164 non-resource cities (NRC) [76], and the regression findings are subsequently presented in Table 5. Columns (4) and (5), respectively, present the regression outcomes for the RC and NRC sample sets. The analysis reveals that the coefficient associated with the DID policy variable is not only positive but also achieves statistical significance at the 10% level for both RC and NRC, indicating that the CET policy is efficacious in affecting the LGUE of these two types of cities. However, based on the size of the DID policy variable coefficient, the magnitude of the policy's effect can be inferred; the effect of the CET policy is 0.0654 in RC and 0.0277 in NRC, which decisively demonstrates that the policy's effect is more pronounced in RC relative to NRC.

The reason for this may lie in the fact that most RC depend on the exploitation and transformation of the indigenous forestry resources, mineral resources, and natural resources as the foundations of their economies. However, these cities often neglect innovation and rely solely on resource dividends to drive the rapid development of the local economy, which results in higher carbon emissions, so CET policies will play a better role. NRC exhibit a more advanced technological level relative to RC, so the development of green finance starts from a high point. NRC are mostly dominated by tertiary industries and they have better economic conditions, which allow them to obtain more green investment projects for green and low-carbon transformation; thus, the CET policy will have limited performance.

The sample is categorized into eastern, central, and western areas according to the geographical location of each city [46]. According to columns (3)–(4) of Table 5, it becomes evident that the estimated coefficient corresponding to the policy variable DID demonstrates a positively valued and statistically important outcome, as shown in column (3). The results indicate that the CET policy promotes green land use efficiency only in the eastern cities and has no significant influence on either the central or the western parts of the country. This disparity could stem from the eastern cities' stronger socioeconomic characteristics, higher technological levels, greater production efficiency, and more rational land planning, which makes the CET policy's influence prominent in these cities. Secondly, a number of industries in the eastern region, distinguished by their highly polluting and energy-intensive nature, have migrated to the central and western regions, which results in serious environmental pollution in the central and western cities and the low LGUE of these cities, thus indicating no substantial influence on the central and western regions. Thirdly, to foster regional balance, the central administration has augmented land provisions for the central and western domains since 2003, thereby proportionately decreasing the land availability for the east. Consequently, the execution of CET policies in eastern cities necessitates a heightened emphasis on the enhancement of the urban LGUE [77,78].

5. Discussion

CET constitutes a crucial focal point for China in its pursuit of the "double carbon" objective, and the transformation and adjustment of industrial activities triggered by this policy cannot be separated from land as the basic carrier. The enhancement of LGUE is an inevitable choice to achieve the optimal allocation of land resources and the comprehensive green transformation of the economy and society. This study focuses on the city level by incorporating the CET pilot policy and urban LGUE into the same framework, which is of greater research value compared with some studies that only study LGUE at the provincial level or in a local area [24,79].

Regarding land use assessment, numerous studies neglect to incorporate social and environmental welfare outputs [21], while certain studies exclusively measure the economic yield per land unit [18]. This paper addresses the limitations of prior research by constructing a more comprehensive "green" framework. Employing the super-efficiency SBM model, as depicted in Table 1, it introduces urban green space as an anticipated output and incorporates three industrial waste streams along with carbon dioxide emissions as unintended outputs to quantify the urban LGUE, in harmony with the notion advanced by Liu [63]. Secondly, this study reveals the marked spatial concentration of the LGUE, with southern regions exhibiting greater LGUE than their northern counterparts and the western LGUE surpassing that of the central and eastern zones [63,69]. Owing to the variations in the LGUE measurement methodologies across studies, this finding reflects common research trends but does not fully align with them.

Currently, it is recognized that the implementation of CET catalyzes the transition of land use towards economic advancement in designated trial zones [80]. In the course of empirical research, using the method of progressive double differences, it is found that the CET pilot policy and urban LGUE have a significant positive impact, and their marginal utility gradually increases. The outcomes obtained in the present study align with the conclusions drawn in Ma's preceding scholarly investigations [81]. Through the DID model, CET creates a notable improvement in LUE, primarily observed in the experimental zones, and the extent of this improvement is highly connected to the regional situational elements. This work extends the existing literature to embrace the dimension of LGUE, which is more potent in driving urban transitions towards greener, low-carbon regimes. A series of robustness checks is incorporated in this investigation, substantiating the credibility of the study's conclusions and verifying Hypothesis 1. Subsequently, this paper delves into the variability of the policy effects, further substantiating Hypothesis 1 based on the described findings. Relative to non-resource-dependent cities and midwestern municipalities, the CET policy exerts a more conspicuous effect in resource-endowed cities and eastern urban centers.

Drawing upon the favorable influence of the CET pilot policy on urban LGUE, the policy can encourage policymakers to embrace green, low-carbon, and efficient methods. The outcomes of this study offer valuable insights for the formulation of analogous policies in other nations, furnishing a reference and research foundation for the enhancement of the urban LGUE. Consequently, this paper offers the following policy recommendations.

First, employ tailored land use strategies based on the spatial arrangement of the LGUE. For regions with relatively high LGUE values, the administration can cautiously boost its land use intensity, concurrently preserving the ecological integrity. Conversely, in areas characterized by lower LGUE, more emphasis should be placed on the promotion of low-carbon, sustainable land use practices. It is necessary to demarcate functional land classifications, such as ecological conservation redline areas, permanently protected farmland regions, and concentrated urban development zones, specifying the land usage and development density within each category to prevent harmful development and avoid wasteful land consumption. It is also necessary to explicitly outline the land use intensity and developmental thresholds for every region, to prevent chaotic urban sprawl and unnecessary land depletion. Ultimately, it is necessary to foster enhanced inter-regional communication and cooperation concerning land management and urban planning and facilitate the exchange of successful experiences and best practices to collaboratively drive the advancement and optimization of the urban LGUE across regions.

Secondly, given the remarkable enhancements in the urban LGUE evidenced by the pilot CET program, it is advisable to broaden its geographical coverage. On the basis of the existing successful experience, the government should actively consider extending the policy to a wider geographical area and expanding the scope of the pilot program, with a view to implementing it in more cities and regions across the country and even across regions. This will not only help to strengthen the role of the market mechanism in resource allocation for energy conservation and emission reduction, but will also be conducive to the formation of a scale effect that will accelerate the application of green and low-carbon technologies and the optimization and upgrading of the industrial structure, which will in turn increase the overall LGUE and optimize the overall layout of the country's land.

Thirdly, based on the heterogeneity that exists in the effects of the CET policy's implementation, it is recommended that the CET policy support for resource-based and eastern cities be increased, including increased policy publicity and promotion and the improved efficiency and strength of policy implementation. It is necessary to provide more policy support and incentives for resource-based cities and eastern cities, such as formulating clearer regulations and incentives for the implementation of CET policies to motivate businesses to actively participate in carbon emissions trading. It is also necessary to set up more pilot projects with RC and eastern cities as the key areas and gradually promote the CET policy through demonstration projects, so as to promote the improvement of the LGUE in cities. Efforts could include strengthening the carbon emission regulation and law enforcement in RC and eastern cities, strictly enforcing the CET policy, preventing enterprises from violating the emissions regulations, and promoting the improvement of the urban LGUE.

This study examined the effects of the CET policy on the LGUE as an addition to earlier research on the consequences of government policies on LUE. However, there were some limitations. (1) In the selection of the sample, starting from the prefecture-level city, it can be enlarged and extended to the district, county, and enterprise levels in subsequent research. (2) In the calculation of urban LGUE indicators, the input and output elements are still not comprehensive enough; in addition to the consideration of financial and ecological benefits, social benefits can be included as outputs in the scope of measurement. (3) We did not thoroughly examine the path of the CET pilot policy's effect on the urban LGUE, such as industrial structure upgrading, etc., which can be fully investigated in future work.

6. Conclusions

Land serves as a fundamental substrate for the development of low-carbon urban environments. The issue of how to promote the transformation of the land structure and improve the LGUE needs to be solved in the global effort to attain a high standard of economic prosperity. Few studies have included the CET pilot policy and urban LGUE in the same framework. Thus, this paper systematically and comprehensively examines the impact of the carbon financial policy, China's CET pilot, on the LGUE and draws a number of valuable conclusions. It enriches the theoretical results and practical experience in the related fields of carbon financial policy and urban LGUE.

In this investigation, the CET pilot initiatives and urban LGUE are integrated within a unified analytical framework. Employing panel data spanning the period from 2011 to 2020 for 278 Chinese prefectural-level cities, the progressive double-difference method is applied to evaluate the influence of the CET pilot policy on the LGUE. The core findings of this research are summarized as follows.

(1) The LGUE is measured by the super-efficient SBM model, and the spatial distribution map shows that the spatial clustering of the LGUE is obvious, with the LGUE of central and western cities being higher than that of eastern cities, and the LGUE metrics in southern urban locales are generally more elevated compared to those in the north. The LGUE shows a "U"-shaped change from 2011 to 2020.
(2) Through the asymptotic double-difference model and empirical tests, the study's outcomes reveal that the implementation of the CET pilot program has led to a substantial enhancement in the LGUE levels within Chinese cities. In comparison to non-CET-participating cities, the pilot cities have witnessed a marked rise in their LGUE values. It is important to emphasize that this beneficial impact does not materialize instantaneously; instead, it exhibits a transient lag feature, coupled with intermittent fluctuations. As the process of policy rollout progresses and the breadth of the pilot program widens, the tangible effects of policy enforcement become increasingly discernible over time. Furthermore, these aforementioned conclusions retain their statistical significance following an array of meticulous robustness checks.
(3) In examining the influence of the CET pilot initiative on LGUE, regional disparities emerge. Notably, when scrutinizing the varied geographical contexts, it is discovered that the CET pilot policy does not exert a statistically significant influence on LGUE within the central or western regions. Conversely, the eastern region exhibits a substantial and meaningful response to the CET pilot policy concerning LGUE improvements. Furthermore, the heterogeneous nature of the CET pilot policy's impact on LGUE is also evident between RC and NRC. Both RC and NRC have seen significant changes in LGUE under the CET pilot policy, yet the extent of its effect varies. More specifically, the CET pilot policy demonstrates a stronger effect on LGUE within RC compared to its impact on NRC.

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