INSTITUTE FOR GLOBAL PROSPERITY

COURSEWORK TITLE

Assessing the Impact of Circular Economy Demonstration City Program on Carbon Emissions in China: A Pathway to Achieving Dual Carbon Goals

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MODULE CODE: BGLP0005

WORD COUNT: 14025

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Abstract

In September 2020, China announced its ambitious goal of "Carbon Peaking and Neutrality" within 40 years at the 75th United Nations General Assembly, known as the "Dual Carbon" targets. This declaration marks a significant step in China's commitment to addressing global climate change and fostering an all-encompassing green transformation of its economy and society. Against this backdrop, the circular economy (CE) has been identified as a pivotal strategy for realizing these carbon goals. The circular economy aims to promote a comprehensive cycle of production, consumption, and social development to achieve both environmental protection and economic growth. Since the initiation of China's Circular Economy Demonstration City policy in 2013, 101 regions (including 62 cities) have joined the initiative. The research will address questions about the impact of the Circular Economy Demonstration City policy on carbon emissions across China and how do CE practices aid in achieving the 'Dual Carbon' targets. The study is anticipated to conduct an empirical investigation based on panel data from 287 prefecture-level cities from 2009 to 2021, aiming to evaluate the impact of China's Circular Economy Demonstration City policy on carbon emissions. The objective is to determine the effectiveness of the circular economy in achieving the nation's 'Dual Carbon' targets and provide comprehensive insights for future policy refinements.

Key words: Circular Economy, Demonstration City Policies, Carbon emissions, China

1. Introduction

China has made significant strides towards environmental sustainability, particularly evident with its declaration of the 'Dual Carbon' targets at the 75th United Nations General Assembly. These targets aim for China to peak carbon emissions before 2030 and achieve carbon neutrality by 2060, reflecting a transformative agenda that seeks to harmonize environmental stewardship with economic development. The Circular Economy (CE) practices play a pivotal role in this transition, and the focus of this dissertation is on China's Circular Economy Demonstration City (CEDC) policy, which has enrolled 101 regions, including 41 cities, since its initiation in 2013. The CEDC policy embodies a strategic approach to promoting sustainable urban development by integrating circular economy principles into the urban fabric. These principles emphasize the efficient use of resources, waste reduction, and the adoption of renewable energy, thereby fostering an economic model that is decoupled from non-renewable resource consumption. This policy is a crucial element in China’s broader strategy to achieve its 'Dual Carbon' goals, addressing both environmental and economic dimensions.

The significance of this research is multifaceted, addressing critical aspects of policy effectiveness, urban sustainability, and economic development. The theoretical commitment to sustainability needs to be operationalized within urban development frameworks, translating high-level policy goals into actionable measures. This study investigates the practical implementation of CE policies in urban settings, focusing on the outcomes versus the intentions behind these policies. By examining the impact of the CEDC policy on carbon emissions, this research provides valuable insights into the policy's efficacy. It identifies potential discrepancies between policy objectives and actual outcomes, highlighting deficiencies in policy formulation and execution that may hinder the achievement of environmental and economic goals. The findings of this research are crucial for policymakers aiming to refine and enhance CE strategies to balance economic growth with environmental sustainability.

This dissertation is driven by two central research questions: To what extent has the Circular Economy Demonstration City (CEDC) policy influenced carbon emissions in Chinese cities? If the CEDC has impacted urban carbon emissions, how does it specifically influence carbon emissions? Addressing these questions is important as it not only evaluates the overall effectiveness of the CEDC policy but also delves into the mechanisms through which the policy exerts its influence. Understanding these mechanisms is essential for refining the policy to enhance its impact and for providing insights that can be applied to other regions and contexts.

The structure of this dissertation is designed to systematically explore the impact of the CEDC policy on carbon emissions and its broader implications for sustainable urban development. The literature review provides a comprehensive examination of existing research on circular economy practices, urban sustainability, and policy effectiveness. It contextualizes the CEDC policy within the broader framework of environmental and economic strategies and identifies gaps in the current research that this dissertation aims to address.

The research design outlines the methodology, including the research questions, methods, models, and data sources. This dissertation employs a quantitative analysis approach, utilizing secondary data and econometric techniques to evaluate the impact of the CEDC policy on carbon emissions. The empirical results section presents the findings of the analysis, including descriptive statistics, benchmark regression results, and robustness tests. It delves into the dynamic effects of the CEDC policy and the heterogeneity analysis between resource-based and non-resource-based cities. The discussion section interprets the empirical findings and explores their implications for policy development and implementation. It examines the underlying mechanisms through which the CEDC policy influences carbon emissions, particularly focusing on the role of government expenditure on energy conservation and environmental protection. This section provides recommendations for optimizing CE strategies to enhance their effectiveness. Finally, the conclusions summarize the key findings of the research, highlighting the contributions of the study to the broader understanding of sustainable urban development. It suggests areas for future research and emphasizes the importance of integrating economic, financial, and urban development policies with environmental sustainability goals. By addressing the operational challenges of implementing CE principles and linking policy effectiveness with tangible environmental and economic outcomes, this dissertation aims to offer data-driven insights that will support policymakers in refining and scaling strategies to achieve sustainable development goals. This rigorous empirical approach is essential for informing policy evolution that aligns with both national ambitions and global environmental commitments.

In summary, the CEDC policy is a cornerstone of China's strategy to achieve its 'Dual Carbon' targets, and this dissertation seeks to provide a thorough evaluation of its impact on carbon emissions. Through a detailed empirical analysis, this study aims to enhance our understanding of how CE policies can be effectively implemented to promote sustainable urban development and contribute to the broader goals of environmental sustainability and economic growth.

2. Literature Review

The relationship between economic growth and environmental sustainability has been a significant focus of research, particularly in the context of carbon emissions. The concept of decoupling economic growth from environmental degradation, as supported by Knight and Schor (2014), suggests that high-income countries can continue to grow economically while maintaining stable or even reducing carbon emissions. This concept has been particularly influential in the development of "green growth" strategies, which aim to reconcile economic progress with environmental sustainability through innovations in energy efficiency and technology. Empirical evidence from regions such as the European Union has shown that it is possible to achieve economic growth alongside a reduction in carbon emissions. For instance, between 1990 and 2017, the European Union experienced a 58% increase in GDP while simultaneously reducing greenhouse gas emissions by 22% (European Environment Agency, 2019). This success is often attributed to strong environmental policies, technological advancements, and a shift towards cleaner energy sources.

However, the concept of decoupling has its limitations, particularly when applied to developing countries. In these regions, the reliance on carbon-intensive industries and technologies presents significant challenges to achieving decoupling. Moreover, the focus on technological innovation as the primary means of achieving decoupling has been critiqued for being overly optimistic, especially in contexts where structural economic changes are necessary (Stern, 2018). Saidi and Omri (2020) have emphasized the importance of renewable energy and technological innovation in achieving decoupling. Their research highlights how integrating renewable energy into the energy mix of major energy-consuming countries can drive economic growth while reducing carbon emissions. This approach not only decreases dependence on fossil fuels but also stimulates economic activity by creating jobs and industries centered around renewable energy. The global transition to renewable energy has been widely studied, with organizations like the International Renewable Energy Agency (IRENA) documenting its economic and environmental benefits. IRENA (2020) suggests that doubling the global share of renewables by 2030 could lead to a 1.1% increase in global GDP, a 70% reduction in emissions, and the creation of millions of jobs in the renewable energy sector. These findings underscore the potential of renewable energy to support sustainable economic growth while addressing climate change. Technological innovation in energy efficiency is another critical component of decoupling. The International Energy Agency (IEA, 2019) has reported that improvements in energy efficiency could contribute to over 40% of the emissions reductions needed to meet global climate targets by 2040. Innovations such as smart grids, energy-efficient appliances, and improved building insulation have significantly reduced energy consumption across various sectors. These advancements have played a crucial role in enabling high-income countries to decouple economic growth from carbon emissions. Despite the significant potential of renewable energy and technological innovation in driving the transition to a low-carbon economy, there is concern that an exclusive focus on these solutions may oversimplify the complex socio-political challenges involved. The transition to renewable energy requires more than technological progress; it necessitates comprehensive policy frameworks that address economic, social, and political barriers to widespread adoption. For instance, without supportive and inclusive policies, the deployment of renewable energy infrastructure can exacerbate existing inequalities, as regions with more resources or stronger political support may advance more quickly, while disadvantaged areas continue to rely on carbon-intensive energy sources, further entrenching their economic and environmental vulnerabilities (Mazzucato and Semieniuk, 2018). Moreover, the social acceptance of renewable energy projects is often influenced by local contexts, including community involvement and the perceived fairness of the benefits and burdens associated with these projects. Public engagement and participation are therefore essential to ensure that communities are actively involved in decision-making processes. Resistance to projects such as wind farms can arise when local communities feel excluded or perceive that the projects will bring more harm than benefit to their area. Thus, effective public engagement strategies are necessary to build trust, secure community support, and ensure that the transition is both equitable and inclusive (McNeish et al., 2021). Additionally, industry cooperation is crucial for the successful implementation of renewable energy technologies. The energy transition requires collaboration among governments, private companies, and civil society organizations to align efforts toward common goals. However, this cooperation is often challenged by competing interests, regulatory hurdles, and the entrenched influence of fossil fuel industries, which may resist the shift to cleaner energy sources. Coordinated policy efforts are required to incentivize industry participation while ensuring that the transition does not disproportionately benefit large corporations at the expense of smaller businesses or marginalized communities (Fouquet, 2016). Furthermore, the benefits of technological advancements in renewable energy are not always evenly distributed, leading to potential inequalities if not carefully managed. While renewable energy projects can create jobs and stimulate local economies, these benefits are not always accessible to all segments of society. There is a risk that the economic gains from the energy transition could be concentrated in wealthier regions or among more affluent populations, leaving vulnerable groups further marginalized. Addressing these inequalities requires targeted policies that ensure equitable access to the opportunities created by the transition, such as job training programs, subsidies for low-income households, and measures to support communities adversely affected by the shift away from fossil fuels (Heffron and McCauley, 2017).

Another critique of the decoupling approach is its focus on economic growth as the primary goal. Jackson (2017) argues that even when economic growth is decoupled from environmental degradation, it may still fail to address other critical aspects of sustainability, such as social well-being, equity, and ecological resilience. Jackson suggests that relying on GDP as the main indicator of progress can result in policies that prioritize short-term economic gains over long-term sustainability. This critique is reflected in the broader debate over the limitations of GDP as a measure of prosperity. The "Beyond GDP" movement, supported by the OECD and the European Commission, advocates for alternative indicators that capture a more comprehensive picture of well-being. These include measures of health, education, environmental quality, and social cohesion, which are often neglected in traditional economic analyses. The movement towards these broader measures reflects an increasing recognition that economic growth alone does not necessarily lead to improved quality of life or environmental sustainability (Stiglitz et al., 2018). The degrowth movement offers a more radical critique, arguing that perpetual economic growth is incompatible with the finite resources of the planet. Scholars like Schneider et al.(2010) propose that instead of pursuing continuous growth, societies should focus on achieving well-being and ecological balance through the deliberate downscaling of economic activity. Degrowth proponents argue that such an approach is necessary to reduce environmental pressures and enhance quality of life, particularly in affluent societies where over-consumption is a significant issue. The unequal distribution of environmental impacts also challenges the decoupling narrative. Wiedmann et al. (2013) have shown that high-income countries, while succeeding in decoupling to some extent, are still responsible for a disproportionate share of global resource consumption and carbon emissions. This finding suggests that decoupling in

wealthy nations often comes at the expense of increased environmental degradation in developing countries, where much of the production and resource extraction takes place.
In response to these critiques, there has been a growing call for a more holistic approach to sustainability that integrates economic growth with broader goals of well-being and prosperity. The Sustainable Development Goals (SDGs) established by the United Nations in 2015 embody this broader perspective by including objectives related to poverty reduction, health, education, gender equality, and environmental sustainability. The SDGs reflect an understanding that economic growth must be pursued in a way that is inclusive and environmentally sustainable, ensuring that all people can share in the benefits of development. Inclusive green growth, as advocated by the World Bank (2012), aims to reduce environmental impacts while ensuring that the benefits of growth are widely shared. This approach involves creating jobs in green industries, improving access to essential services, and addressing inequalities within and between countries. The concept of "well-being economies," which prioritizes health, social equity, and environmental sustainability over mere economic output, has gained traction as an alternative framework for measuring progress. Countries like New Zealand and Bhutan have adopted national well-being frameworks that measure success based on indicators such as mental health, community vitality, and environmental quality rather than GDP alone (OECD, 2020). These approaches reflect a shift towards a more integrated understanding of sustainability, where economic growth is viewed as a means to an end rather than an end in itself. This perspective aligns with the growing recognition that true prosperity requires not just economic growth but also the protection of natural resources, the reduction of inequalities, and the enhancement of social well-being. By broadening the focus of sustainability policies to include well-being and prosperity, it is possible to create more resilient and inclusive economies that are better equipped to address the complex challenges of the 21st century. This approach requires rethinking economic priorities and developing new frameworks for measuring progress that go beyond GDP to capture the full range of factors that contribute to human and environmental well-being.
One of the most promising frameworks that embodies this broader approach to sustainability is the circular economy (CE). By rethinking traditional linear economic models, which prioritize consumption and waste, the circular economy offers a pathway to achieving not only environmental sustainability but also economic resilience and social well-being. The CE model focuses on creating closed-loop systems where resources are reused, recycled, and regenerated, minimizing waste and reducing the environmental impact of economic activities (Schützenhofer et al., 2022). This shift from a linear to a circular approach aligns with the need to develop new frameworks for measuring progress, as it emphasizes long-term prosperity and ecological balance over short-term economic gains.
The origins of the CE concept are linked to earlier theories focused on sustainability, such as the "cradle to cradle" design philosophy, which advocates for products to be designed with

consideration for their entire life-cycle. Similarly, the concept of "industrial ecology," which proposes that industries should mimic natural ecosystems where the waste of one process serves as the input for another, underscores the interconnectedness and interdependence essential to a circular economy (Stahel, 2016). The term ‘circular economy’ was formally introduced by Pearce and Turner (1990), promoting an economic system where resources are reused, repaired, and recycled to extend their life cycles. For instance, Germany's Closed Substance Cycle and Waste Management Act in 1996 laid a foundational legal framework that inspired similar developments across the continent (Matten, 1996). These efforts reflect a broader recognition of the need to decouple economic growth from resource consumption and environmental degradation. In the 21st century, the concept of the CE has evolved significantly, driven by scholarly and policy interests and a growing recognition of the need to shift from traditional, linear consumption and production models to more sustainable, circular practices. This transition emphasizes sustainability as a core component of economic systems and business models, moving beyond mere waste reduction (Geissdoerfer et al., 2017). A widely recognized definition by the Ellen MacArthur Foundation (2016) describes CE as "restorative and regenerative by design," aiming to maintain the highest utility and value of products, components, and materials, and distinguishing between technical and biological cycles. Further analysis by Kirchherr et al. (2017) has identified the rapid adoption of CE principles by businesses and governments as a response to increasing resource scarcity and environmental degradation. Their work highlights how CE has been conceptualized as a solution to enhance resource efficiency and foster economic resilience. Moreover, the expansion of the CE concept into various sectors, including manufacturing, agriculture, and energy, reflects its adaptability and wide-reaching potential to transform economies (Lieder and Rashid, 2016). Notably, scholars like Sauvé et al. (2016) argue that the circular economy also presents significant challenges, including the need for comprehensive regulatory frameworks, new business strategies, and consumer behavior changes. They suggest that understanding and overcoming these barriers is crucial for the wider adoption of CE practices.

In recent years, the concept of CE has become increasingly integral to China's environmental and economic policies, reflecting a strategic shift towards sustainable development. China's journey toward a circular economy began in the early 2000s, spearheaded by national policy initiatives that recognized the dual benefits of environmental sustainability and economic efficiency. The pivotal moment came with the promulgation of the Circular Economy Promotion Law in 2008, which laid a robust legislative foundation for the country's CE practices. This law encouraged the reduction of waste, the enhancement of resource recycling, and the promotion of recycling industries, setting the stage for comprehensive national strategies (The Standing Committee of the National People’s Congress China, 2008). The integration of CE principles into China’s economic planning is evident in its inclusion within the Five-Year Plans, which are crucial policy documents that outline the country’s economic priorities and development strategies. The 12th Five-Year Plan (2011-2015), for instance, explicitly aimed to improve resource productivity and environmental quality by promoting the circular economy. This plan set specific targets for the reduction of waste and the increase in the reuse and recycling of key materials (Fan and Fang, 2020). Moreover, the adoption of CE practices has been seen as a strategic response to China's environmental challenges. Announced in 2020, China's commitment to peak carbon emissions before 2030 and achieve carbon neutrality by 2060 represents a significant shift towards an environmentally sustainable economic model (Xinhua, 2021). The circular economy, with its emphasis on resource efficiency and waste reduction, is integral to achieving these carbon targets. By minimizing waste and enhancing the recycling and reuse of materials, CE practices can significantly reduce the energy-intensive processes of raw material extraction, processing, and disposal, which are major sources of carbon emissions.

Current research on the development of CE in China predominantly remains at the macro level, with limited studies assessing the specific practical effects of this strategy within the Chinese context. One critical observation made by McDowall et al. (2017) highlights that while CE principles are robustly discussed at policy and strategic levels, there is a distinct lack of empirical research into their practical applications and the real-world efficacy of these policies. The study points out that there is an ongoing need for detailed, practical evaluations that can bridge the gap between theoretical frameworks and actual outcomes, facilitating better policy adjustments and implementations tailored to specific local conditions. Further, Zhu and Geng (2011) highlight the theoretical advancement of CE but acknowledge the slow adoption and integration at the enterprise and municipal levels, pointing to the need for more concrete evidence on the effectiveness of CE practices in achieving sustainable economic and environmental outcomes. The research illustrates that while the principles of CE are increasingly integrated into policy frameworks, there is a significant lag in actionable data that confirms the efficacy of these policies on a granular level, thus hindering targeted improvements and adaptations. Therefore, this study will use China's Circular Economy Demonstration City policy as a representation of its practical application, investigating the policy's impact on carbon emissions in China. This approach will allow us to evaluate its effectiveness in helping China achieve its Dual Carbon goals and provide insights into how to optimize and adjust China-specific circular economy policies.

3. Research Design for Empirical Analysis

3.1 Research questions

The circular economy aims to maintain the value of products, materials, and resources in the economy for as long as possible by promoting practices such as sharing, leasing, reusing, repairing, refurbishing, and recycling. These practices are intended to extend the lifecycle of materials, thereby reducing waste, conserving resources, and lowering greenhouse gas emissions. By fundamentally altering the way resources are consumed and managed, the circular economy concept has the potential to significantly impact carbon emissions. In 2008, China enacted the Circular Economy Promotion Law, embedding the concept of the circular economy into the national development strategy from a legal perspective. This law mandates comprehensive planning, resource efficiency, waste reduction, and the promotion of recycling across various industries (CECC, 2008). It supports sustainable practices in production, encourages the use of renewable resources, and emphasizes government promotion and market orientation. This legal framework provided institutional support for promoting circular economy practices and facilitated the development of various pilot and demonstration projects across the country. The concept has gradually been implemented and promoted in practice.

In 2013, the National Development and Reform Commission officially designated 40 regions as the first batch of Circular Economy Demonstration Cities (Counties), marking an important milestone in the practice of the circular economy (NDRC, 2013). Through the Circular Economy Demonstration City policy (CEDC), the circular economy concept has been integrated into the development of industry, agriculture, and the service sector, as well as urban infrastructure construction. The policy promotes circular production methods and green lifestyles across all stages of production, distribution, and consumption, aiming to build a comprehensive resource recycling system that covers the entire society, popularize a green circular culture, and drive green and low-carbon development through circular development. This, in turn, enhances the ecological civilization level of cities. With China announcing its "dual carbon" goals at the 75th United Nations General Assembly—peaking carbon emissions before 2030 and achieving carbon neutrality by 2060—the urgency and necessity of achieving environmental sustainability have become even more pronounced. Therefore, by integrating the CEDC with China's dual carbon goals, this study primarily addresses the research question:

To what extent has the Circular Economy Demonstration City Policy (CEDC) influenced carbon emissions in Chinese cities?

Although the circular economy is theoretically recognized as beneficial for environmental sustainability, its actual effectiveness requires empirical validation. Evaluating the actual effectiveness of the CEDC not only reveals its performance in different cities but also helps identify potential obstacles and challenges in the implementation process. The carbon emission is one of the main drivers of global climate change, and reducing carbon emissions is a core measure in combating climate change. The carbon emission indicator comprehensively reflects a region's environmental governance status, including efforts in energy structure adjustment, industrial production transformation, and the application of green technologies (Zhang et al., 2024). By analyzing carbon emission data, it is possible to fully evaluate the actual effectiveness of the policy in environmental governance and sustainability. Furthermore, this study may provide information and guidance for urban policymakers, helping them refine and expand circular economy strategies to achieve better environmental and economic outcomes. After initially understanding the implementation effects of the CEDC, this study aims to further investigate:

If the CEDC has impacted urban carbon emissions, how does it specifically influence carbon emissions?

It is insufficient to merely evaluate whether a policy is effective; it is also necessary to understand the specific mechanisms through which the policy influences carbon emissions. This involves understanding the specific measures, key factors, and intervention points in the policy implementation process. To further explore this issue, this study uses municipal government expenditure on energy conservation and environmental protection as an intermediary variable to examine whether the CEDC influences carbon emissions through this expenditure. By analyzing this expenditure indicator, it is possible to uncover the actual operations and investment of the CEDC at the municipal level. The total expenditure on energy conservation and environmental protection, as a comprehensive fiscal indicator, can effectively reflect the execution intensity and priority of policies. This indicator encompasses various aspects of expenditure, including environmental protection management, environmental monitoring and supervision, pollution control, and sustainable development investments (Zhang and Dong, 2023).

By comprehensively understanding these dimensions, this study aims to provide scientific guidance for improving and promoting more effective circular economy strategies, thereby advancing environmental governance and sustainable development in China and globally. In the context of global climate change, China's dual carbon goals are not only a national strategic requirement but also an important part of global environmental governance. Therefore, studying the impact of the CEDC on carbon emissions not only helps achieve China's environmental goals but also provides valuable lessons and references for global sustainable development. Through an in-depth exploration of the implementation of the CEDC and its mechanisms of impact on carbon emissions, this study aims to provide policymakers and the academic community with a more comprehensive understanding and more empirical-based recommendations. This not only helps to optimize existing policies but also provides important references for the design of future policies, contributing to the realization of the dual carbon goals.

3.2 Research method

To examine the impact of the CEDC on carbon emissions, this study employs a quantitative analysis approach. Quantitative analysis is characterized by the systematic empirical investigation of observable phenomena through statistical, mathematical, or computational techniques (Ostrov and Hart, 2013). This method is particularly suited for this research due to its capacity to handle large datasets, provide objective measurements, and yield reproducible results. The ability to establish patterns and relationships between variables through quantitative analysis is crucial for evaluating the effectiveness of policies such as the CEDC. Quantitative methods are selected for their robustness in controlling for confounding variables, thereby isolating the specific effects of the CEDC on carbon emissions. This approach enhances the reliability of the findings and ensures that the results are valid and generalizable to similar contexts. The precision offered by quantitative analysis is indispensable for policy evaluation, allowing for meticulous examination of data and establishment of clear causal relationships. For example, quantitative methods have been widely acknowledged for their effectiveness in policy evaluation due to their ability to provide empirical evidence and statistical rigor (Nyankori, 1996).

Data collection for this study relies predominantly on secondary sources, including municipal government statistical yearbooks and the National Energy Statistical Yearbook. Secondary data refers to data originally collected by other researchers or institutions, often for different purposes. This data collection method offers several advantages: it is time-efficient, cost-effective, and provides access to a wealth of information that might otherwise be inaccessible (Dunn et al., 2015). The reliability and validity of secondary data from official sources are typically high, as these data are systematically collected and meticulously documented, ensuring accuracy and consistency. This authenticity enhances the credibility of the research findings. However, the use of secondary data is not without challenges. Issues such as missing data for specific regions or years can arise, potentially impacting the comprehensiveness of the analysis. To address these challenges, methods such as data imputation, interpolation, or the use of proxy variables will be employed. Data imputation involves replacing missing values with substituted values based on statistical estimates, thereby maintaining the dataset's integrity (Aljuaid and Sasi, 2016). Interpolation, on the other hand, estimates missing values within the range of the known data points. Both methods ensure that the dataset remains robust and representative of the entire study period and regions. Additionally, using proxy variables can substitute for missing data by leveraging related or similar data points.

The analysis will be conducted using an empirical research approach, which involves the observation and measurement of phenomena to derive knowledge from actual experience rather than from theory alone. Empirical research is particularly advantageous for this study as it provides direct evidence of the CEDC policy's impact on carbon emissions, based on real-world data. By employing econometric models, this study will apply statistical methods to economic data, thereby giving empirical content to economic relationships. This approach enables a thorough examination of the causal relationship between the CEDC policy and carbon emissions while accounting for potential confounding factors. Econometric techniques such as statistical inference and parameter estimation will be utilized to analyze the data. Statistical inference allows researchers to make predictions or inferences about a population based on a sample of data, while parameter estimation involves determining the values of parameters within an economic model. These techniques will enable the assessment of the CEDC policy's direct and indirect effects on carbon emissions, incorporating municipal government expenditure on energy conservation and environmental protection as an intermediary variable. This intermediary variable serves to explore whether the CEDC influences carbon emissions through changes in government spending. The models will be specified to capture the complex dynamics of these relationships, providing a nuanced understanding of the policy's impact. Moreover, the analysis will consider both the economic and statistical significance of the results. Economic significance pertains to the practical or real-world importance of the findings, while statistical significance refers to the probability that the observed effects are not due to chance. Ensuring that both aspects are addressed is crucial for substantiating the research hypotheses. Only when the results demonstrate both economic and statistical significance can they be used to validate the effectiveness of the CEDC policy. This dual consideration ensures that the findings are not only statistically valid but also practically relevant, providing robust evidence for policy recommendations (Kennedy, 2008). The empirical analysis will be further enriched by incorporating advanced econometric methods such as fixed effects and random effects models to control for unobserved heterogeneity. Fixed effects models account for time-invariant characteristics of the cities that could influence carbon emissions, thus isolating the effect of the CEDC policy. Random effects models, on the other hand, assume that individual city effects are random and uncorrelated with the independent variables, providing another layer of robustness to the analysis. By comparing the results from these models, it is possible to ensure the robustness and reliability of the findings (Hsiao, 2014).

When conducting empirical analysis for this research, it is also crucial to ensure integrity, respect for data privacy, and adherence to professional standards as outlined in the ASA Ethical Guidelines (ASA, 2021). The use of secondary data in this research is categorized as low ethical risk for several reasons. The data are sourced from government or national institutions' statistical yearbooks and related official documents, ensuring that their use does not infringe on any proprietary rights or ethical guidelines. Furthermore, the empirical analysis involves statistical modeling and does not require interaction with human subjects, thereby eliminating the risk of harm or discomfort to participants. By relying on secondary data, the research avoids potential ethical issues related to informed consent and confidentiality breaches. This approach upholds high ethical standards while ensuring the reliability and validity of the research findings.

In summary, by leveraging robust statistical techniques and reliable data sources, the study aims to generate insightful and actionable findings. These findings will contribute to the advancement of circular economy strategies and the achievement of environmental sustainability goals in China and globally. This methodological approach not only enhances the understanding of the CEDC policy's effectiveness but also provides valuable recommendations for policymakers, facilitating the optimization of existing policies and the design of future interventions.

3.3 Research model

In examining the impact of the Circular Economy Demonstration City (CEDC) policy on carbon emissions, this study utilizes the Staggered Difference-in-Differences (DID) method. This approach is particularly well-suited for the analysis given the staggered implementation of the CEDC policy across different cities and at different times. The staggered DID method allows for a more refined analysis of the policy's impact by leveraging variations in the timing of the policy implementation, thereby providing a dynamic assessment of its effects on carbon emissions over time. The Staggered DID method builds upon the traditional DID approach by accommodating treatment effects that occur at different points in time. This method offers significant advantages in terms of its ability to handle heterogeneous treatment timings and to provide more accurate causal estimates by exploiting the temporal variation in policy implementation. By comparing treated and control groups over multiple time periods, the staggered DID method effectively controls for both time-invariant unobserved heterogeneity and common trends that could influence the outcome variable (Athey and Imbens, 2022). This is particularly relevant to the CEDC, which began with the first batch of demonstration cities in 2013 and expanded with a second batch in 2015 (NDRC, 2013; NDRC, 2015). The staggered nature of the CEDC policy's roll-out makes the staggered DID method a perfect fit for this analysis.

The research model can be specified as follows:

$$\ln CO2_{it} = \alpha + \beta did_{it} + \gamma X_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

In this model, $\ln CO2_{it}$ represents the logarithm of carbon emissions of city i in period t. The parameter α is the intercept term, while β represents the estimated parameter, capturing the impact of the CEDC on carbon emissions. γ is another estimated parameter. The explanatory variable did_{it} is defined as $treat_i \times time_t$, where $treat_i = 1$ for cities that are part of the treatment group (i.e., those designated as CEDCs) and $treat_i = 0$ for control group cities. The variable $time_t = 1$ indicates the period after the implementation of the CEDC policy, and $time_t = 0$ indicates the period before its implementation. The X_{it} vector represents a set of control variables that account for other factors influencing carbon emissions, such as economic activity, industrial structure, energy consumption, and local environmental policies. The term μ_i denotes the city fixed effects, which control for unobserved characteristics that are specific to each city and do not vary over time. The term δ_t represents the time fixed effects, which control for common shocks affecting all cities in a given time period. Finally, ε_{it} is the disturbance term, capturing random errors. This model facilitates the decomposition of the policy's impact into components associated with the timing and nature of the intervention, thereby providing a detailed understanding of its effects. The inclusion of city and time fixed effects ensures that the analysis accounts for both spatial and temporal variations, enhancing the robustness of the estimated impacts

(Angrist and Pischke, 2008). By employing the Staggered DID method, this study aims to provide a comprehensive evaluation of the CEDC policy’s effectiveness in reducing carbon emissions. The staggered nature of the policy’s implementation across different cities offers a unique opportunity to exploit temporal variations and gain insights into the dynamic effects of the policy. This approach not only strengthens the causal inference but also helps identify the specific mechanisms through which the CEDC policy influences carbon emissions.

The Staggered DID method is particularly beneficial in the context of the CEDC policy because it allows for the examination of how the policy's impact evolves over time as different cities adopt the circular economy practices at different stages. This staggered rollout provides a natural experiment setting that can be leveraged to understand the nuances of policy implementation and its effectiveness. The findings from this analysis are expected to inform policy decisions and contribute to the optimization of future interventions aimed at achieving China’s dual carbon goals and enhancing global environmental governance.

3.4 Research data

This study utilizes a dataset comprising 287 cities from 2009 to 2021. The policy implementation began in 2013, so the initial four years serve as a baseline period to analyze pre-policy and post-policy changes. Comparing data before and after policy implementation allows for a clearer understanding of the policy’s actual impact and effectiveness. The year 2021 is chosen as the endpoint because it provides the most recent data, ensuring the timeliness and validity of the study results. The independent variable (did), representing the cities that issued the CEDC policy, is selected from the official list by the National Development and Reform Commission (NDRC) of China (NDRC, 2013). Since this study focuses on prefecture-level cities, 41 variables were retained after excluding county-level cities and special regions. The dependent variable (lnCO2), which measures carbon emission intensity, is sourced from major publications such as the China Energy Statistical Yearbook, China City Statistical Yearbook, and China Energy Statistical Yearbook. The calculation methodology follows Cong et al. (2014), considering three scopes of emissions:

Scope 1: All direct emissions within the city's jurisdiction, including emissions from transportation, buildings, industrial processes, agricultural and forestry activities, land-use changes, and waste management.

Scope 2: Indirect emissions related to energy consumption outside the city's jurisdiction, mainly including emissions from purchased electricity, heating, and cooling to meet urban consumption.

Scope 3: Other indirect emissions not covered in Scope 2, including emissions from the production, transportation, use, and waste disposal of goods purchased from outside the city.

The sum of these three scopes provides the raw emission data. To enhance model stability and predictive performance, the raw data were log-transformed, facilitating the interpretation of relationships between variables. Data for other control and mediating variables are obtained from the National Bureau of Statistics and the statistical yearbooks of the respective cities (NBS, 2021). The meaning of each variable are placed in Table 1.

Table 1
Variable Design Table

Type	Symbol	Name
Dependent Variable	lnCO2	Carbon Emission
Independent Variable	did	CEDC
Control Variables	gdp	Economic Development Level
	fin	Financial Development Level
	fdi	Degree of Openness to Foreign Investment
	urban	Urbanization Rate
	gov	Degree of government intervention
	road	Infrastructure Development
Mediating Variable	ep	expenditure on energy conservation and environmental protection

4. Empirical Results

4.1 Descriptive statistics

In analyzing the factors influencing carbon emissions, a dataset with 3638 observations is utilized, and various statistical operations are performed in Stata. Out of the total observations, 3330 are in the control group, while the remaining 308 belong to the treated group. Summary statistics for the variables are generated, revealing key insights. For instance, the standard deviation for gdp is 0.605, reflecting considerable variation in economic development levels among the regions studied. The detailed descriptive statistics, including means, standard deviations, minimums, and maximums, are presented in Table 2. Figure 1 shows the distribution of prefecture-level cities implementing the CEDC policy. In the legend, 1 indicates cities that implemented the policy in 2013, and 2 indicates cities that implemented the policy in 2015.

Table 2
Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
lnCO2	3638	7.933	.206	7.617	8.149
did	3638	.085	.278	0	1
gdp	3638	10.653	.605	9.227	12.018
fin	3638	1.001	.571	.308	3.22

fdi	3638	.017	.017	0	.08
urban	3638	.548	.153	.25	.946
gov	3638	.195	.092	.073	.564
road	3638	.842	.359	.179	2.169

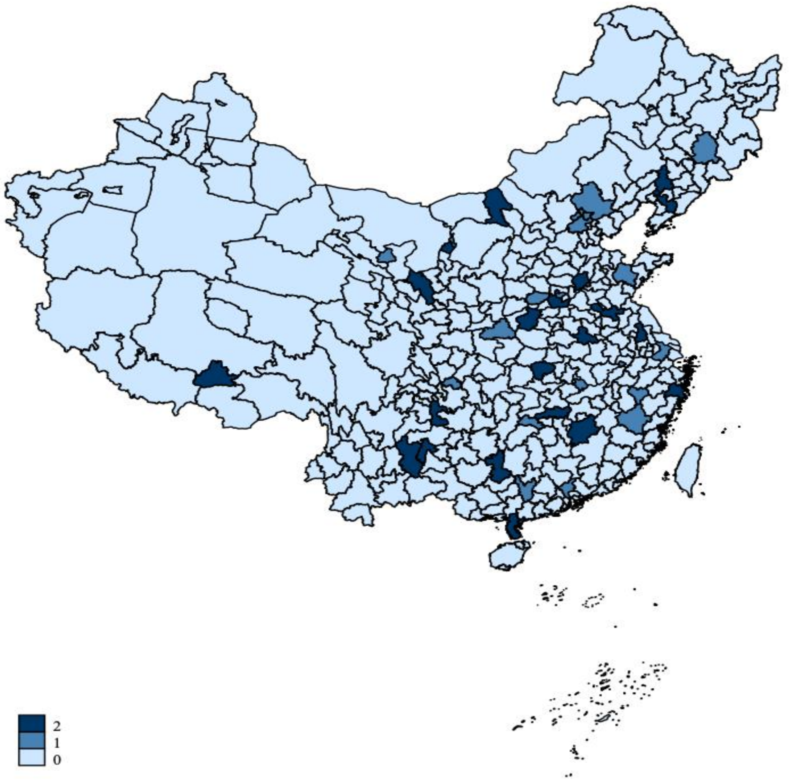

Figure 1 Spatial distribution of the CEDC cities

In Table 3, the pairwise correlations between the variables in the dataset reveal several important insights into the relationships influencing carbon emissions. Notably, there is a statistically significant negative correlation between carbon emissions (lnCO2) and the CEDC variable (did), with a correlation coefficient of -0.058 ($p<0.01$). This suggests that regions with CEDC presence tend to have slightly lower carbon emissions, which is a crucial finding for the primary focus of this research. Additionally, the financial development level (fin) shows a positive and statistically significant correlation with carbon emissions, indicating that regions with higher financial development tend to have higher carbon emissions. In contrast, the degree of openness to foreign investment (fdi) has a negative and significant correlation with carbon emissions, suggesting that more open regions tend to have lower emissions. Other significant correlations among control variables include a strong positive relationship between economic development (gdp) and urbanization rate (urban), and a significant negative correlation between economic development and government intervention (gov). These correlations highlight the interconnected nature of these factors and underscore the importance of considering multiple dimensions when analyzing the determinants of carbon emissions.

Table 3
Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) lnCO2	1.000							
(2) did	-0.058***	1.000						
(3) gdp	0.021	0.151***	1.000					
(4) fin	0.052***	0.046***	0.356***	1.000				
(5) fdi	-0.050***	-0.039**	0.264***	0.119***	1.000			
(6) urban	0.024	0.108***	0.760***	0.518***	0.261***	1.000		
(7) gov	-0.050***	-0.018	-0.503***	0.085***	-0.253***	-0.333***	1.000	
(8) road	-0.043***	0.115***	-0.127***	0.059***	-0.038**	-0.163***	0.397***	1.000

**** p<0.01, ** p<0.05, * p<0.1*

4.2 Benchmark regression

The analysis examines different models in Table 4 to understand the effect of CEDC presence (did) on carbon emissions, controlling for various factors and fixed effects.

The Column (1) includes only the independent variable did and controls for both individual and year fixed effects. The results indicate that CEDC presence has a statistically significant negative effect on carbon emissions, suggesting that cities with the CEDC policy tend to have lower carbon emissions. Both Column (2) and Column (3) show that the results for the did variable remain consistent with the first column, further supporting the initial finding that the CEDC policy is associated with reduced carbon emissions. Noteworthy values in these models include the significant positive effect of GDP on carbon emissions, indicating that higher economic development levels are associated with higher emissions. The urbanization rate has a significant positive effect in both models, indicating that higher urbanization is linked to increased emissions. The lack of significance for “road” may suggest that infrastructure development does not have a direct or immediate impact on carbon emissions, or that the effect is captured by other variables such as economic development and urbanization. In the final Column (4), city-level cluster robust standard errors are used to avoid potential heteroscedasticity problems, and both year and city fixed effects are controlled. The coefficient for did remains negative and statistically significant at the 1% level. This fixed-effects regression further corroborates the initial experimental findings, strengthening the evidence that the CEDC policy is associated with reduced carbon emissions.

Overall, the preliminary results across all models consistently show that the presence of the CEDC policy is associated with a reduction in carbon emissions. This relationship remains robust after controlling for different fixed effects, suggesting the potential effectiveness of the

CEDC policy in mitigating carbon emissions. However, further analysis is needed to confirm these findings and demonstrate the robustness of the results.

Table 4

Benchmark regression results

	(1)	(2)	(3)	(4)
VARIABLES	lnCO2	lnCO2	lnCO2	lnCO2
did	-0.040***	-0.053***	-0.032**	-0.038***
	(0.014)	(0.014)	(0.013)	(0.014)
gdp		0.068***	0.035***	0.062***
		(0.010)	(0.011)	(0.014)
fin		0.013	0.027***	-0.001
		(0.008)	(0.006)	(0.009)
fdi		-0.865***	-0.877***	-1.032***
		(0.208)	(0.192)	(0.209)
urban		0.178***	0.081**	0.112**
		(0.049)	(0.037)	(0.056)
gov		0.061	-0.185***	0.187***
		(0.061)	(0.055)	(0.068)
road		-0.011	-0.006	-0.018
		(0.012)	(0.010)	(0.012)
Constant	7.937***	8.568***	8.290***	8.537***
	(0.003)	(0.095)	(0.116)	(0.154)
Observations	3,636	3,636	3,638	3,636
R-squared	0.565	0.558	0.034	0.574
City FE	Yes	Yes	No	Yes
Time FE	Yes	No	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

4.3 Robustness tests

4.3.1 Parallel trend test

The parallel trend test is crucial for the validity of staggered DID results as it ensures that the treatment and control groups exhibit similar trends before the intervention (Riveros-Gavilanes, 2023). This similarity allows for a more accurate estimation of the treatment effect, isolating the impact of the intervention from other factors that might influence the outcome. To verify if the cities in the treatment and control groups exhibit parallel trends prior to the CEDC implementation, the following test model is established:

$$\mathrm{lnce}_{it} = \alpha + \sum_{k=-4}^{8} \rho_k D_{i,n+k} + X_{it}\varepsilon + \eta_i + \theta_t + \epsilon_{it}$$

In this model, α represents a constant term. The variable $D_{i,n+k}$ is a dummy variable that equals 1 if the treated city implemented the CEDC policy k years after 2013. ε is a set of estimated coefficients for the control variables (X_{it}). The year denotes the start of the CEDC policy, which is 2013 in this case. To avoid perfect multicollinearity, $D_{i,n-1}$ is excluded from the model. η_i captures the individual fixed effects, θ_t represents the time fixed effects, and ϵ_{it} is the error term that captures random fluctuations and other unobserved factors affecting the outcome variable.

The estimated coefficients and their corresponding standard errors are then plotted in the Figure 2 to illustrate the impact of CEDC implementation over time. From the figure, it can be observed that the estimated coefficients for the pre-treatment periods do not show significant deviations from zero, suggesting that the cities in the treatment and control groups followed similar trends before the CEDC implementation. Following the implementation of the policy, the coefficients begin to show notable changes, highlighting the effect of the CEDC policy over time. This result supports the assumption of parallel trends, validating the staggered DID approach in assessing the impact of the CEDC policy.

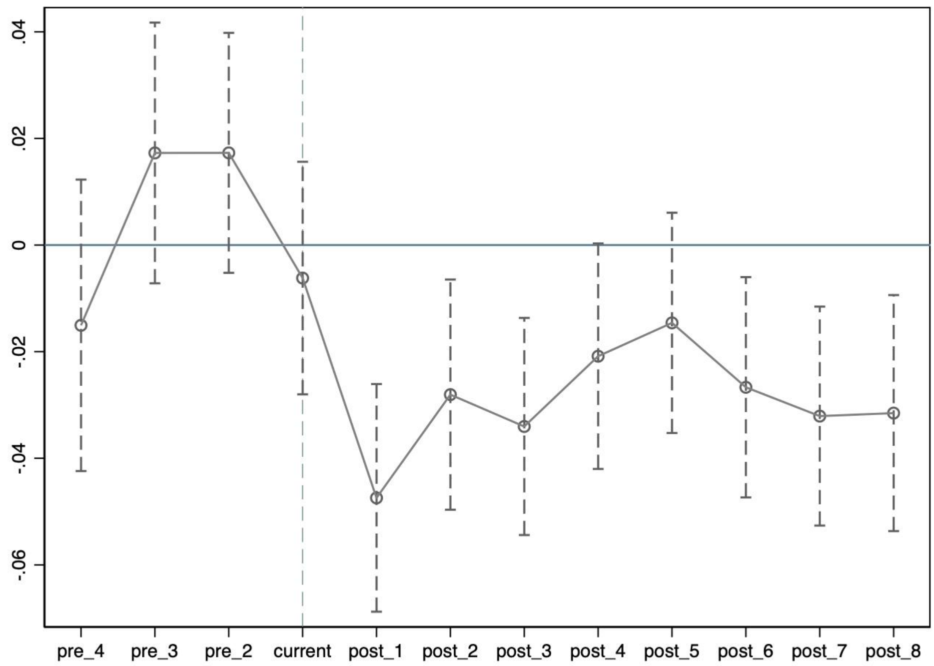

Figure 2 Parallel Trend Test Results

4.3.2 Placebo test

In the benchmark model of this research, some influencing factors are controlled. However, there may still be omitted variables that affect carbon emissions. To address this, a random selection of policy implementation times is conducted within the sample, followed by regression using the benchmark model. This process is repeated 1000 times, resulting in 1000 regression coefficients. Figure 3 illustrates the distribution of these 1000 regression coefficients after random sampling, with the dashed line representing the true regression coefficient of this study. Theoretically, the 1000 regression coefficients should not be significant, indicating that the randomly sampled samples should not exhibit an effect on reducing carbon emissions. As shown, most coefficients are uniformly distributed around zero, and the mean of the 1000 regression coefficients is close to zero, which is significantly different from the true regression coefficient of -0.038. This finding suggests that the carbon reduction effect of CEDC is not coincidental and is not influenced by unobservable factors.

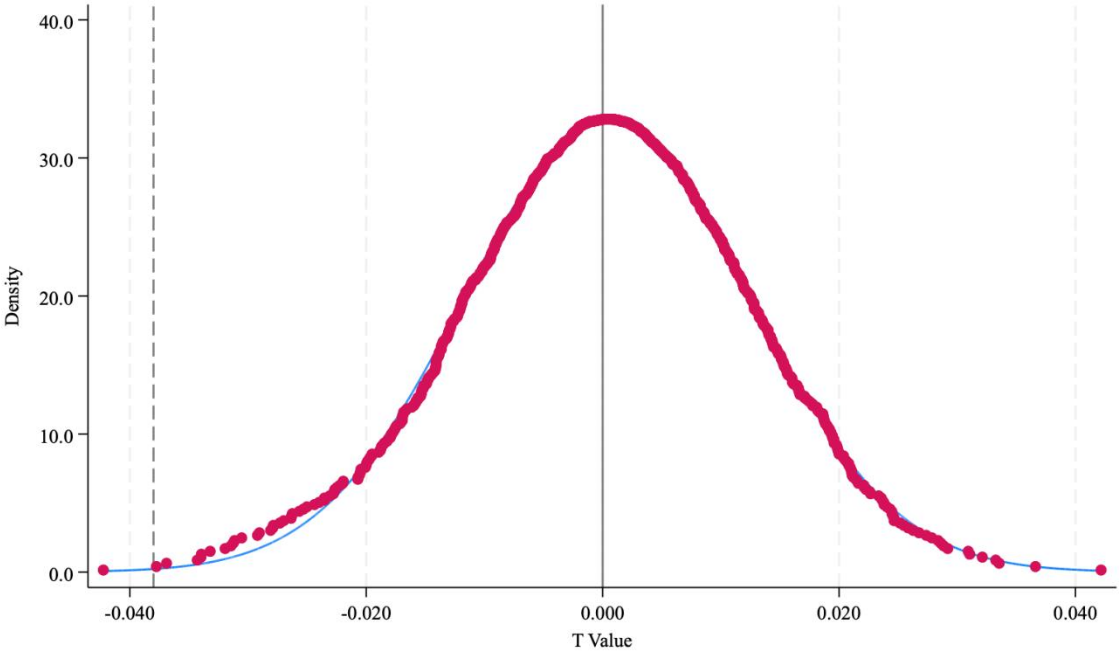

Figure 3 Placebo test results

4.3.3 PSM-DID

The DID method requires a random assignment to treatment and control groups to avoid significant biases in the results. However, the selection of CEDC cities might be influenced by factors such as higher energy consumption (Fan and Zhang, 2021). To address the endogeneity issues arising from this selection bias, the research employs the Propensity Score Matching (PSM) technique. PSM is a statistical method used to control for confounding variables and reduce selection bias by matching treated and control units with similar characteristics. According to Rosenbaum and Rubin (1983), PSM helps to create a balanced comparison group that mimics random assignment, thereby enhancing the credibility of causal inferences. This step ensures a more accurate estimation of the policy's impact by mitigating selection bias before applying the DID analysis. The logistic model for PSM is constructed as follows:

$$\mathrm{logit}(\mathrm{dv_{it}} = \lambda) = \beta_0 + \beta_j X_{it} + \varepsilon_{it}$$

$\mathrm{dv_{it}}$ is a dummy variable of the policy. When $\lambda = 1,$ city i is designated as a CEDC city; When $\lambda = 0,$ city i is designated as other cities. The covariates X_{it} include all of the control variables. The matching method utilized a 1:1 nearest neighbor approach, with the balance test results displayed in Figure 4. It is evident that after matching, the biases for nearly all covariates significantly decreased, approaching zero. This indicates that post-matching, the distribution of covariates between the treatment and control groups became much more similar, enhancing the balance of the matching process and the reliability of the estimation results, thus passing the balance test.

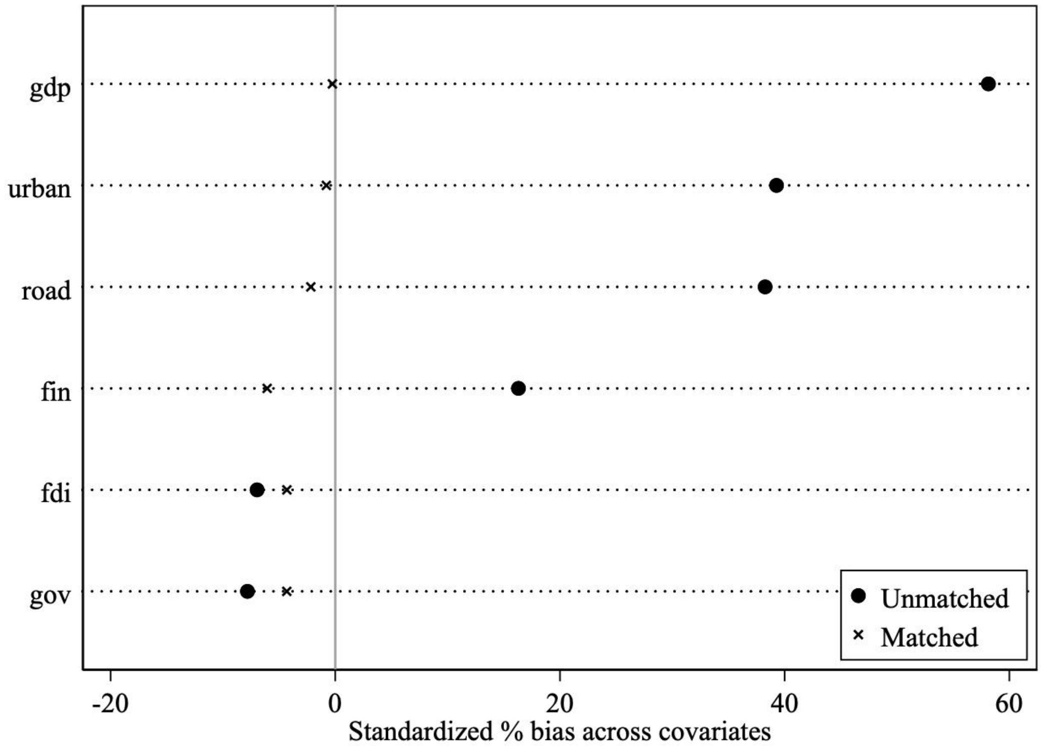

Figure 4 PSM balance test results

After applying the 1:1 nearest neighbor matching, 823 observations remained in the dataset. As shown in Table 5, the regression results indicate that the CEDC policy still exhibits a significantly negative regression coefficient after matching. This finding further substantiates the robustness of the baseline study conclusions. Additionally, the balance test confirms that the matching process has effectively reduced bias, ensuring that the treatment and control groups are comparable in terms of covariates, thus enhancing the credibility of the regression analysis.

Table 5
PSM-DID results

	(1)
VARIABLES	lnCO2
did	-0.037**

	(0.016)
gdp	0.037
	(0.026)
fin	0.038**
	(0.015)
fdi	-1.663***
	(0.310)
urban	0.200**
	(0.082)
gov	-0.167
	(0.113)
road	0.010
	(0.020)
Constant	8.235***
	(0.277)
Observations	823
R-squared	0.088
City FE	Yes
Time FE	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5. Further Analysis

5.1 Heterogeneity analysis

5.1.1 Dynamic effects

In 2013, the CEDC policy was implemented in 19 cities, and in 2015, an additional 22 cities adopted the policy. This staggered implementation provides a unique opportunity to analyze and compare the effects of the CEDC policy across these two distinct phases. The following analysis delves into the differential impacts of the policy over time, with a particular focus on understanding how the timing of implementation influences the effectiveness of the CEDC policy in reducing carbon emissions.

The empirical results (Table 6) reveal that the effects of the CEDC policy vary significantly between the two implementation phases. In 2013, the coefficient for did1 is -0.006 with a standard error of 0.027, indicating a negligible and statistically insignificant impact on carbon emissions. This initial lack of significant impact suggests that the cities implementing the policy in 2013 might have required an adjustment period to integrate the CEDC measures effectively. It is possible that the initial phase involved setting up regulatory frameworks, training personnel, and aligning industrial practices with the new policy requirements, thereby delaying observable reductions in emissions. In contrast, the 2015 implementation, represented by did2, shows a statistically significant negative coefficient of -0.046 with a standard error of 0.021 (p<0.05). This result suggests that the cities adopting the CEDC policy in 2015 experienced a notable reduction in carbon emissions. The more pronounced effect in 2015 could be attributed to several factors. Firstly, the earlier implementation in 2013 may have set a precedent, creating a learning effect that enhanced the efficiency and effectiveness of subsequent implementations. Cities implementing the policy in 2015 might have benefited from the experiences and best practices developed during the earlier phase. Additionally, the cumulative effect of more cities adopting the policy could have amplified the overall impact, as widespread adoption may lead to more significant environmental benefits through collective action and regional cooperation.

The analysis also controls for various factors influencing carbon emissions, providing a comprehensive view of the dynamics at play. Economic development consistently shows a positive and significant impact on carbon emissions, with coefficients of 0.072 in both models. This indicates that higher economic development levels are associated with increased emissions, underscoring the environmental challenges linked to economic growth. The degree of openness to foreign investment exhibits a significant negative effect on emissions, suggesting that regions more open to foreign investment tend to adopt cleaner technologies and practices, leading to lower emissions. Urbanization shows a significant positive impact on emissions, highlighting the increased energy consumption and industrial activity associated with urban areas. Interestingly, infrastructure development does not show a statistically significant impact on carbon emissions in either model. This lack of significance suggests that infrastructure development alone may not directly influence emissions, or that its effects are mediated by other factors such as economic activity and urbanization. Government intervention also remains statistically insignificant in both models, indicating that the measured level of intervention does not have a clear impact on emissions within the context of this analysis.

Overall, the findings suggest that the CEDC policy's effectiveness in reducing carbon emissions becomes more evident over time, particularly with the broader implementation observed in 2015. The temporal dynamics highlighted in this analysis emphasize the importance of sustained policy efforts and the potential for cumulative benefits through widespread adoption. Further research is needed to confirm these findings and explore the long-term impacts of the CEDC policy, considering additional years of data and potential lag effects.

Table 6

Dynamic effects

	(1)	(2)
VARIABLES	lnCO2	lnCO2
did1	-0.006	
	(0.027)	

did2		-0.046**
		(0.021)
gdp	0.072***	0.072***
	(0.010)	(0.010)
fin	0.012	0.011
	(0.008)	(0.008)
fdi	-0.834***	-0.850***
	(0.213)	(0.213)
urban	0.170***	0.169***
	(0.049)	(0.049)
gov	0.057	0.060
	(0.061)	(0.061)
road	-0.017	-0.017
	(0.012)	(0.012)
Constant	8.616***	8.614***
	(0.095)	(0.095)
Observations	3,636	3,636
R-squared	0.556	0.557
City FE	Yes	Yes
Time FE	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

5.1.2 Heterogeneity between Resource-based cities and Non-resource based cities

Understanding the heterogeneity between resource-based cities (RBCs) and non-resource-based cities (NRBCs) is crucial for analyzing the impact of circular economy practices on carbon emissions. Resource-based cities typically depend heavily on industries such as mining, manufacturing, and heavy industry, which are more polluting and resource-intensive. In contrast, non-resource-based cities often have more diversified economies with greater emphasis on services and high-tech industries, leading to different environmental and economic dynamics. Resource-based cities are characterized by their dependence on the extraction and processing of natural resources. This dependence often leads to significant environmental degradation and higher levels of pollution due to the nature of their industrial activities (Xu et al., 2021). These cities face challenges such as heavy pollution, low industrial efficiency, and an irrational industrial structure, which necessitate a distinct approach to implementing circular economy practices. The heavy reliance on resource extraction and processing industries means that RBCs typically have higher initial levels of carbon emissions. However, these cities also present significant opportunities for emission reductions through targeted circular economy initiatives that focus on improving resource efficiency, promoting industrial symbiosis, and enhancing waste management practices (Superti et al., 2021). In contrast, non-resource-based cities generally have more diverse economic structures with a significant presence of service and technology sectors. These cities often benefit from higher levels of innovation and technological adoption, which can facilitate the implementation of circular economy practices. The economic activities in NRBCs are typically less carbon-intensive compared to RBCs, leading to relatively lower levels of carbon emissions. However, the challenge in NRBCs lies in further decoupling economic growth from carbon emissions and integrating circular economy principles into urban planning, infrastructure development, and consumer behavior (Song et al., 2022).

Empirical findings (Table 7) from the study indicate significant differences in the impacts of circular economy initiatives on CO2 emissions between RBCs and NRBCs. In RBCs, circular economy initiatives have led to a notable reduction in CO2 emissions. The did coefficient for CO2 reduction in RBCs is -0.064 ($p < 0.01$), highlighting a significant decrease due to these initiatives. Conversely, in NRBCs, the impact of circular economy initiatives on CO2 emissions has been minimal, with a DID coefficient of 0.003, suggesting that the measures might not be sufficient to drive significant changes in these cities. The study also reveals a positive correlation between GDP growth and CO2 emissions in both RBCs and NRBCs. In RBCs, the GDP coefficient is 0.067, while in NRBCs, it is slightly higher at 0.082. This indicates that economic growth still drives emissions in both types of cities. Foreign direct investment shows a more substantial negative impact on CO2 emissions in NRBCs compared to RBCs, suggesting differences in how FDI influences carbon emissions across these cities. Urbanization impacts CO2 emissions differently in RBCs and NRBCs. In NRBCs, urbanization significantly increases emissions (0.269, $p < 0.05$), likely due to increased construction and transportation activities. In RBCs, the impact is not statistically significant. Infrastructure improvements reduce emissions in RBCs but have a slight positive effect in NRBCs (0.021), reflecting differences in urban planning and transport efficiency.

Table 7

RBCs and NRBCs heterogeneity analysis

	(1)	(2)
	Resource-based	Non-resource based
VARIABLES	lnCO2	lnCO2
did	-0.064***	0.003
	(0.018)	(0.022)
gdp	0.067**	0.082***
	(0.024)	(0.021)
fin	-0.027	0.021
	(0.014)	(0.015)
fdi	-0.715*	-1.323***
	(0.301)	(0.330)
urban	-0.008	0.269**

	(0.077)	(0.093)
gov	0.383***	-0.141
	(0.082)	(0.123)
road	-0.062***	0.021
	(0.016)	(0.017)
Constant	8.691***	8.649***
	(0.261)	(0.244)
Observations	2043	1593
R-squared	0.550	0.610
City FE	Yes	Yes
Time FE	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.2 Mediation analysis

Mediation analysis is a research method used to reveal the complex relationships between variables. When examining the effect of a certain cause on an outcome, mediation analysis helps us understand how this process occurs. It introduces one or more mediating variables to elucidate the channels and mechanisms through which the cause influences the outcome. The benefit of using mediation analysis lies in its ability to provide deeper insights, enabling us to understand not only whether a cause is effective but also why it is effective. For instance, this study aims to investigate whether the CEDC policy influences urban carbon dioxide emissions through the mediating variable of government expenditure on energy conservation and environmental protection. Through this analysis, we can more precisely understand the role of such expenditure in the policy implementation process. This not only aids in evaluating the overall effectiveness of the policy but also informs future policy optimization and resource allocation, making them more targeted and effective.

According to Jiang (2022), the causal relationship between the mediating variable M and the dependent variable Y is typically straightforward in theory and relatively close in terms of logic and timing. Therefore, it is sufficient to provide adequate literature evidence for the relationship from M to Y without using formal causal inference methods. The research should specifically focus on the effect of the explanatory variable X on the mediating variable M. Even though formal mediation analysis tests may sometimes face limitations due to data and methodological constraints, this simplified analysis strategy can still offer valuable insights, helping us understand the specific mechanisms and pathways through which policies or interventions exert their effects.

The relationship between government expenditure on energy conservation and environmental protection and urban CO2 emissions has been extensively studied. Various authoritative sources highlight how this expenditure influences emissions reduction through different mechanisms. For instance, a study by Dogan and Turkekul (2016) demonstrated that government environmental spending reduces CO2 emissions by promoting technological innovation and strict regulatory enforcement. Similarly, research by Dong et al. (2018) emphasized that such spending leads to significant environmental benefits by funding renewable energy projects and enhancing regulatory frameworks. Further supporting this, Qu et al. (2022) investigated the impact of green investment in China and found that increasing fiscal expenditures on environmental protection significantly boosts green technological progress and economic growth, thereby reducing carbon emissions. This research aligns with the findings of Wang and Zhou (2023), who demonstrated that government support for green initiatives is crucial for maintaining momentum in environmental progress and achieving economic benefits through technological advancements. Additionally, Zhang et al. (2020) conducted an analysis of fiscal decentralization and urban industrial pollution emissions in China, revealing that local environmental protection expenditures enhance regional environmental quality by strengthening pollution governance and environmental infrastructure construction. This indicates that localized government spending effectively reduces urban CO2 emissions by addressing specific regional pollution issues and enhancing local environmental capacities.

These studies collectively reinforce the critical role of government expenditure on energy conservation and environmental protection in reducing urban CO2 emissions. The convergence of findings from different contexts and regions provides a robust basis for understanding the mechanisms at play. Government investments in green technologies, stringent environmental regulations, and local environmental governance improvements are consistently shown to contribute to significant reductions in carbon emissions. This body of evidence supports the use of mediation analysis to explore how CEDC policy impact urban carbon emissions through these specific expenditure mechanisms. By synthesizing these authoritative sources, we gain a comprehensive understanding of the multifaceted role of government spending in promoting sustainable urban development and achieving carbon reduction targets.

Building on this established relationship between government environmental expenditure and CO2 emission reductions, this research investigates the impact of the CEDC policy on government expenditure in energy conservation and environmental protection. The analysis aims to determine whether the CEDC policy acts as a significant explanatory variable (X) influencing the mediating variable (M), which is the government expenditure on energy conservation and environmental protection. Our study employs a detailed empirical analysis to uncover the effects of the CEDC policy on government expenditure. The data set comprises observations across multiple cities, incorporating various control variables to ensure robustness and reliability of the results. Our primary dependent variables include carbon emissions (lnCO2) and government expenditure on environmental protection (EP).

The regression results (Table 8) indicate that the CEDC policy has a statistically significant impact on EP. Specifically, the coefficient for the did estimator for EP is 0.113 ($p < 0.05$), suggesting that the CEDC policy is associated with a substantial increase in government expenditure on energy conservation and environmental protection. This finding aligns that targeted environmental policies can effectively mobilize resources towards environmental initiatives. In addition to the impact of the CEDC policy, the control variables provide further insights into the dynamics at play. The positive and significant coefficient for GDP on EP (0.790, $p < 0.01$) underscores the dual relationship between economic growth and environmental impacts, as well as the increased fiscal capacity to invest in environmental protection. This result is consistent with the findings of Xue et al. (2023), who demonstrated that economic growth enhances the ability of governments to fund green initiatives, thereby supporting environmental progress. Similarly, the positive coefficient for urbanization reflects the challenges and opportunities presented by urban development in managing environmental sustainability. Urbanization often necessitates increased government spending on environmental protection to mitigate the adverse effects of rapid urban growth. Interestingly, the coefficient for foreign direct investment is negative but not significant for EP (-1.166, $p > 0.1$), suggesting that while foreign direct investment may contribute to emissions reductions through technology transfers and efficiency improvements, it does not directly influence government expenditure patterns in a statistically significant way. This finding is somewhat unexpected and warrants further investigation into the specific channels through which FDI affects environmental outcomes. Furthermore, the coefficient for government intervention is positive and significant for EP (2.325, $p < 0.01$), indicating that higher government revenue enhances the ability to fund environmental protectio-n initiatives. This supports the notion that fiscal capacity is crucial for implementing effective environmental policies.

In summary, this part utilizes mediation analysis to explore the impact of the CEDC policy on urban carbon dioxide emissions through the mediating variable of government expenditure on energy conservation and environmental protection. This research builds on literature that highlights the crucial role of government spending in promoting environmental sustainability and reducing CO_2 emissions. The empirical analysis reveals that the CEDC policy significantly increases government expenditure on environmental protection, which in turn effectively reduces CO_2 emissions. This demonstrates the policy's effectiveness in mobilizing resources towards green initiatives and highlights the critical pathway through which the policy influences urban carbon emissions. Additionally, the control variables provide deeper insights into the dynamics of environmental expenditure, showing significant relationships with economic growth, urbanization, and government revenue.

Table 8

Mediation analysis

VARIABLES	(1) EP
did	0.113**
	(0.046)
gdp	0.790***
	(0.088)
fin	0.063
	(0.056)
fdi	-1.166
	(0.803)
urban	0.964***
	(0.367)
gov	2.325***
	(0.615)
road	-0.016
	(0.062)
Constant	1.776**
	(0.787)
Observations	3,376
R-squared	0.807
City FE	Yes
Time FE	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6. Discussion and Policy Implications

The findings from the empirical analysis of the Circular Economy Demonstration City (CEDC) policy provide valuable insights into the policy's impact on carbon emissions in Chinese cities and highlight important policy implications. This section discusses these findings in detail, exploring the underlying mechanisms and broader implications for policy development and implementation.

One of the key findings of this study is that implementing the CEDC policy significantly reduces carbon emissions. The empirical results, validated through multiple robustness tests, confirm that the CEDC policy's impact on carbon emissions is both significant and consistent across various model specifications. The robustness of these findings underscores the policy's effectiveness as a strategic tool for environmental management. Building on the benchmark regression and robustness test results, it is crucial to delve into the effects of control variables on the relationship between the CEDC policy and carbon emissions. The inclusion of these control variables provides a more comprehensive understanding of the dynamics at play and reveals several additional findings of interest. Firstly, economic development, represented by GDP, consistently shows a positive correlation with carbon emissions. This suggests that higher levels of economic activity are associated with increased emissions, highlighting the challenge of balancing economic growth with environmental sustainability. The positive coefficient for GDP across various models indicates that despite the implementation of the CEDC policy, economic expansion tends to drive up emissions. This underscores the importance of integrating green technologies and sustainable practices into the economic growth model to mitigate its environmental impact. Financial development, measured by the level of financial services and infrastructure, also exhibits a noteworthy relationship with carbon emissions. In several models, financial development shows a positive but less consistent correlation with emissions. This indicates that while financial growth can contribute to economic development, it does not necessarily align with environmental sustainability. On one hand, financial development can lead to greater economic activities that may increase emissions, particularly in emerging markets where industrialization is often prioritized over environmental concerns. On the other hand, a more developed financial sector could potentially facilitate the funding of green projects and technologies, although this is contingent upon a deliberate alignment of financial incentives with environmental goals (Fu et al., 2022). For example, the financial sector's capacity to drive green investments—such as renewable energy projects, energy-efficient technologies, and sustainable infrastructure—remains underutilized in many regions of China (Li et al., 2022). The lack of robust frameworks and incentives for green finance means that financial institutions often prioritize short-term profits over long-term sustainability, thus missing opportunities to contribute significantly to reducing carbon emissions. To address this gap, policies that promote green finance and encourage investment in sustainable projects are crucial. Governments and regulatory bodies could implement measures such as tax incentives for green investments, stricter environmental disclosure requirements, and the development of green bond markets to stimulate sustainable financing. Foreign direct investment (FDI) emerges as a significant factor influencing carbon emissions. The regression results show a negative correlation between FDI and carbon emissions, suggesting that regions with higher levels of foreign investment tend to have lower emissions. This can be attributed to the transfer of advanced, cleaner technologies and practices from developed countries to host regions, which helps in reducing carbon footprints. Encouraging FDI in green industries and technologies could further amplify this positive effect. Urbanization, another critical control variable, presents a complex relationship with carbon emissions. The positive correlation between urbanization and emissions highlights the environmental pressures associated with increasing urban populations and expanding infrastructure. As cities grow, so does their energy consumption and waste production, leading to higher emissions. However, urban areas also have the potential for more efficient resource use and waste management practices. Policies aimed at promoting sustainable urban development and smart city initiatives are essential to harness the benefits of urbanization while mitigating its environmental impact. Government intervention, measured by the degree of government involvement in economic activities, shows mixed results in its relationship with carbon emissions. In some models, higher government intervention correlates with reduced emissions, reflecting the effectiveness of regulatory measures and public investments in environmental protection. However, the significance and direction of this relationship vary across different model specifications, suggesting that the impact of government intervention is context-dependent and may vary based on the nature and enforcement of policies. The analysis also reveals the impact of infrastructure development on carbon emissions. While the coefficient for infrastructure development is not consistently significant, its inclusion in the models helps control for variations in regional infrastructure capabilities. Well-developed infrastructure can facilitate efficient energy use and reduce emissions, but the immediate impact might be captured by other variables like economic development and urbanization.

Overall, the inclusion of control variables in the regression models provides a more nuanced understanding of the factors influencing carbon emissions. It highlights the multifaceted nature of environmental challenges and the need for a holistic approach in policy design and implementation. The findings underscore the importance of integrating economic, financial, and urban development policies with environmental sustainability goals to achieve a balanced and sustainable growth trajectory.

One significant aspect to consider is why the impact of the CEDC policy was not as pronounced in the first batch of pilot cities in 2013 compared to the second batch in 2015. Several factors contribute to this difference in outcomes. Firstly, the initial phase of any large-scale policy implementation often involves substantial learning and adjustment periods. Cities designated in the first batch of 2013 were the pioneers of this ambitious policy. They faced numerous challenges, including lack of experience, initial resistance to change, and the necessity to build new administrative and regulatory frameworks from scratch (Cramer, 2020). These cities had to establish the groundwork for circular economy practices, which often involves a steep learning curve and initial setbacks. In contrast, the cities in the second batch in 2015 benefited from the experiences and lessons learned from the first batch. By 2015, there was a clearer understanding of best practices, more robust regulatory frameworks, and better dissemination of successful strategies. The diffusion of knowledge and improved administrative practices likely contributed to the more pronounced impact observed in the second batch of cities. Additionally, the central government provided more targeted support and resources to the second batch of cities, which included technical assistance and financial incentives aimed at overcoming the initial barriers faced by the first batch. Moreover, technological advancements and innovations in sustainable practices progressed significantly between 2013 and 2015. The rapid development of green technologies, such as renewable energy sources, energy-efficient industrial processes, and waste recycling systems, provided the second batch of cities with more effective tools to implement circular economy principles (Mulvaney et al., 2021). These advancements enabled the newer batch of cities to achieve quicker and more substantial reductions in carbon emissions as they had access to more sophisticated and efficient technologies. Additionally, public awareness and support for environmental sustainability grew between these periods. The increasing public demand for cleaner air and sustainable urban environments likely pressured local governments to enforce the CEDC policies more stringently in the second batch of cities. The enhanced public engagement and support facilitated smoother implementation and greater compliance with the policy measures (Dagilienė et al., 2021).

The dynamic effects of the CEDC policy further illuminate the temporal aspects of its impact on carbon emissions. Initially, the implementation phase may witness a slight increase in emissions due to transitional activities. However, as the policy measures take root, there is a clear and sustained reduction in emissions over time. This cumulative effect highlights the necessity of long-term commitment and consistent policy enforcement to realize meaningful environmental benefits. The gradual yet persistent decline in emissions reflects the time required for structural changes and technological advancements to manifest fully. In summary, the more significant impact observed in the second batch of CEDC cities can be attributed to the accumulation of experience and knowledge from the first batch, the availability of advanced technologies, improved regulatory frameworks, and increased public support. These factors underscore the importance of continuous learning, technological innovation, and public engagement in the successful implementation of environmental policies. The dynamic effects of the CEDC policy thus reflect the evolving capabilities and resources that cities develop over time, leading to progressively better environmental outcomes.

Building on this, the heterogeneity in the policy effects between Resource-Based Cities (RBCs) and Non-Resource-Based Cities (NRBCs) further illustrates the nuanced impact of the CEDC policy. The more pronounced reduction in carbon emissions in RBCs, as compared to NRBCs, can be attributed to several interrelated factors. Firstly, RBCs typically have higher baseline levels of carbon emissions due to their reliance on resource extraction and energy-intensive industries. This structural composition creates a larger margin for improvement when stringent environmental policies like the CEDC are introduced. For instance, Du and Li (2020) argue that industries with higher initial pollution levels exhibit more substantial reductions in emissions when stringent regulations are applied. This indicates that RBCs have a greater potential for emissions reduction simply because they start from a higher level of pollution. Furthermore, the CEDC policy facilitates significant technological advancements and structural economic adjustments in RBCs. The policy's emphasis on technological innovation and industrial upgrading means that RBCs, which are heavily dependent on outdated, high-emission technologies, stand to benefit greatly from the adoption of cleaner, more efficient alternatives. This transition is supported by the literature, which highlights the role of technological innovation in reducing emissions in sectors traditionally associated with high pollution (Ouyang et al., 2020). Additionally, the regulatory and administrative response in RBCs tends to be more stringent due to higher environmental pressures and public health concerns. The populations in these cities are often more exposed to the adverse effects of pollution, leading to stronger public demand for cleaner air and sustainable practices. This societal pressure compels local governments in RBCs to enforce CEDC policies more rigorously, resulting in more significant environmental improvements. Gao and Teets (2020) indicate that local governments in areas with higher environmental degradation are more likely to implement strict environmental policies and achieve better outcomes. Economic diversification is another critical factor driving the more substantial impact of the CEDC policy in RBCs. As traditional industries face regulatory and market pressures to reduce emissions, there is a strategic shift towards diversifying the economic base by investing in greener sectors. The CEDC policy provides the necessary framework and incentives for such transformations. Empirical studies have shown that regions with a higher dependency on resource-intensive industries are more motivated to pursue economic diversification as a strategy for sustainable development (Breul and Nguyen, 2022). In contrast, NRBCs, with their more diversified economic structures and lower baseline pollution levels, exhibit less dramatic but still significant reductions in carbon emissions. The existing economic activities in these cities are generally less carbon-intensive, and the implementation of the CEDC policy builds on a foundation of already relatively lower emissions. Consequently, the marginal impact of the policy is less pronounced compared to RBCs. This differentiation underscores the importance of tailoring environmental policies to the specific economic and structural contexts of different regions to maximize their effectiveness.

In summary, the more pronounced effect of the CEDC policy in RBCs can be attributed to their higher baseline pollution levels, the necessity for substantial technological and structural adjustments, stronger regulatory enforcement driven by public demand, and the strategic push towards economic diversification. These factors collectively contribute to the greater reductions in carbon emissions observed in RBCs, highlighting the importance of context-specific policy design and implementation to achieve significant environmental outcomes.

To address how the CEDC policy specifically influences carbon emissions in Chinese cities, we turn to the mediation analysis that underscores the role of government expenditure on energy conservation and environmental protection. The CEDC policy impacts urban carbon emissions primarily through this mediating variable, serving as a critical pathway for implementing the policy's objectives. The CEDC policy significantly increases government expenditure on energy conservation and environmental protection in Chinese cities. This increased spending is directed towards various initiatives aimed at reducing carbon emissions. These initiatives include investments in renewable energy infrastructure, promotion of energy efficiency in industries and buildings, and development of advanced pollution control technologies. By allocating more resources to these areas, the CEDC policy facilitates the transition from high-emission activities to more sustainable practices. One of the primary mechanisms through which government expenditure impacts carbon emissions is by fostering technological innovation. Investments in research and development for clean technologies enable cities to adopt more efficient and less polluting industrial processes. This is particularly significant in RBCs, where outdated technologies contribute substantially to carbon emissions. The adoption of cleaner technologies reduces the carbon intensity of industrial activities, leading to overall lower emissions. Additionally, government expenditure on environmental protection supports the enforcement of stringent regulatory measures. Increased funding allows for better monitoring and enforcement of environmental regulations, ensuring that industries comply with emission standards. This regulatory pressure compels industries to adopt best practices and technologies that minimize carbon emissions. In RBCs, where public demand for cleaner air is higher due to more severe pollution, stricter enforcement leads to more substantial reductions in emissions. Moreover, the CEDC policy encourages economic diversification. By providing financial incentives and support for developing green industries, the policy reduces reliance on traditional, high-emission sectors. This shift not only lowers carbon emissions but also promotes sustainable economic growth. Diversified economies are better equipped to integrate circular economy principles, further enhancing their environmental sustainability.

7. Conclusions

The primary purpose of this research was to evaluate the effectiveness of the Circular Economy Demonstration City (CEDC) policy in reducing carbon emissions across Chinese cities, with a particular emphasis on understanding how these policies contribute to China's broader "Dual Carbon" goals. These goals aim for China to peak carbon emissions before 2030 and achieve carbon neutrality by 2060. The research sought to fill a significant gap in the empirical evaluation of circular economy practices by assessing the impact of these policies at the urban level, which is crucial for understanding their real-world applicability and effectiveness. The central research questions guiding this study were: To what extent has the CEDC policy influenced carbon emissions in Chinese cities? And if the CEDC has impacted urban carbon emissions, what mechanisms drive this impact? Addressing these questions is vital as they delve into the effectiveness of the policy not only on a macro level but also through the specific channels through which the policy exerts its influence on carbon emissions, thereby providing a more nuanced understanding of its operational dynamics.

The research findings indicate that the CEDC policy has a statistically significant impact on reducing carbon emissions in Chinese cities. This conclusion is robust, as evidenced by various empirical tests and controls that consistently showed reductions in emissions in cities implementing the CEDC policy. Particularly notable is the finding that the impact was more pronounced in cities that adopted the policy in later stages, specifically in the second batch of cities in 2015, compared to the first batch in 2013. This suggests that a learning curve and the accumulation of experience played crucial roles in enhancing the policy's effectiveness. Cities that implemented the policy later likely benefited from the experiences and best practices developed during the initial implementation phase, leading to more efficient and effective outcomes. Additionally, the study revealed significant heterogeneity in the policy's impact between resource-based cities (RBCs) and non-resource-based cities (NRBCs), with RBCs showing more substantial reductions in emissions. This difference is attributed to the higher baseline pollution levels in RBCs, which offered a greater potential for improvement when stringent environmental policies like the CEDC were introduced.

The significance of these results lies in their contribution to the broader discourse on the effectiveness of circular economy policies in achieving environmental sustainability. By providing empirical evidence of the CEDC policy's impact, this research supports the argument that circular economy initiatives, when properly implemented and backed by strong governmental support, can lead to significant reductions in carbon emissions. This evidence is particularly valuable in the context of China's ambitious environmental goals, offering insights that can inform policy refinements and future strategies. The findings also underscore the importance of tailored policy interventions that consider the unique economic and environmental characteristics of different cities. For instance, the pronounced impact in resource-based cities highlights the need for policies that target sectors with the highest potential for emissions reduction, while in non-resource-based cities, the focus might shift to further integrating circular economy principles into urban planning and development.

In terms of contributions, this research advances both theoretical and practical knowledge in the field of environmental policy and urban sustainability. Theoretically, it enriches the understanding of how circular economy practices can be operationalized within urban settings to achieve significant environmental outcomes. By employing rigorous empirical analysis, the study demonstrates that circular economy policies are not merely theoretical constructs but have tangible, measurable impacts when applied in real-world contexts. Practically, the study offers actionable insights for policymakers. It emphasizes the critical role of government expenditure on energy conservation and environmental protection as a mediating factor in the success of the CEDC policy. The findings suggest that targeted financial support is essential for achieving the desired outcomes, particularly in facilitating technological upgrades and ensuring compliance with environmental standards. Additionally, the study highlights the importance of continuous learning and adaptation in policy implementation. The more significant reductions in emissions observed in the second batch of cities suggest that policies are more effective when they evolve based on lessons learned from earlier implementations.

Despite its contributions, this research has several limitations that must be acknowledged. First, the study relies on secondary data, which, while offering breadth, may limit the depth of insights that could be obtained through primary data collection methods such as interviews or case studies. The secondary data used, including carbon emissions statistics and government expenditure records, are dependent on the accuracy and consistency of the reporting entities, which may vary across different cities and time periods. Additionally, the study's focus on Chinese cities, while providing valuable insights into the Chinese context, may limit the generalizability of the findings to other regions or countries with different economic structures and policy environments. This geographical limitation suggests that while the findings are relevant to China, further research is needed to explore the applicability of similar circular economy policies in other countries, particularly those with different levels of economic development and environmental challenges. Another limitation is the study's primary focus on the short to medium-term effects of the CEDC policy. While the research provides a thorough analysis of the policy's impact from its inception in 2013 up to 2021, it does not fully explore the long-term sustainability and scalability of these initiatives. Long-term studies are necessary to understand whether the reductions in carbon emissions observed in the short term are sustainable over decades and whether the policies can be scaled up or adapted to other regions with varying economic and environmental conditions. Moreover, the analysis did not account for potential external factors such as global economic trends, international trade dynamics, or technological advancements outside the scope of the policy that might influence carbon emissions. These factors could have a significant impact on the effectiveness of the CEDC policy and should be considered in future research.

The dynamic effects of the CEDC policy further illuminate the temporal aspects of its impact on carbon emissions. Initially, during the implementation phase, there might be a slight increase in emissions due to transitional activities, such as construction or industrial shifts required to adapt to the new regulations. However, as the policy measures take root, there is a clear and sustained reduction in emissions over time. This cumulative effect highlights the necessity of long-term commitment and consistent policy enforcement to realize meaningful environmental benefits. The gradual yet persistent decline in emissions reflects the time required for structural changes and technological advancements to manifest fully. Building on this, the heterogeneity in the policy effects between Resource-Based Cities (RBCs) and Non-Resource-Based Cities (NRBCs) further illustrates the nuanced impact of the CEDC policy. The more pronounced reduction in carbon emissions in RBCs can be attributed to several interrelated factors. RBCs typically have higher baseline levels of carbon emissions due to their reliance on resource extraction and energy-intensive industries. This structural composition creates a larger margin for improvement when stringent environmental policies like the CEDC are introduced. Moreover, the CEDC policy facilitates significant technological advancements and structural economic adjustments in RBCs. The policy’s emphasis on technological innovation and industrial upgrading means that RBCs, which are heavily dependent on outdated, high-emission technologies, stand to benefit greatly from the adoption of cleaner, more efficient alternatives.

In summary, while the Circular Economy Demonstration City policy in China has shown significant potential in reducing carbon emissions and contributing to the nation's environmental goals, future research should address these limitations and explore the long-term impacts and broader applicability of such policies. By building on the insights gained from this study, policymakers can refine and expand circular economy strategies to achieve more sustainable urban development on a global scale. This approach not only helps China in achieving its "Dual Carbon" goals but also provides valuable lessons for other countries seeking to balance economic growth with environmental sustainability.

8. References

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