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How does low-carbon city construction drive enterprise green governance? A complete chain mediation model

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Abstract

Purpose – In confronting the challenge of climate change and progressing towards dual carbon goals, China is actively implementing low-carbon city pilot policy. This paper aims to focus on the potential impact of this policy on enterprise green governance, aiming to promote the reduction and balance of carbon emissions.

Design/methodology/approach – Based on the panel data of China's large-scale industrial enterprises from 2007 to 2013, this paper uses the Difference-in-differences (DID) method to study the impact and path mechanism of the implementation of low-carbon city pilot policy on enterprise green governance. Heterogeneity analysis is used to compare the effects of low-carbon city pilot policy in different regions, different enterprises and different industries.

Findings – The low-carbon pilot can indeed effectively enhance corporate green governance, a conclusion that still holds after a series of robustness tests. The low-carbon city pilot policy mainly enhances enterprise green governance through two paths: an industrial structure upgrade and enterprise energy consumption, and it improves green governance by reducing enterprise energy consumption through industrial structure upgrade. The impact of low-carbon city pilot policy on enterprise green governance shows significant differences across different regions, different enterprises and different industries.

Research limitations/implications – This paper examines the impact of low-carbon city pilot policy on enterprise green governance. However, due to availability of data, there are still some limitations to be further tackled. The parallel trend test in this paper shows that the pilot policy has a significant positive effect on the green governance of enterprises. However, due to serious lack of data in some years, the authors only selected the enterprise data of a shorter period as our experimental data, which leads the results to still have certain deficiencies. For the verification of the impact mechanism, the conclusions obtained in this paper are relatively limited. Although all the mechanism tests are passed, the reliability of the results still needs to be further tested through future data samples. In addition, as the pilot policy of low-carbon cities is still in progress, the policy can be tracked and analysed in the future as more data are disclosed, and further research can be carried out through dimensional expansion.

Practical implications – Low-carbon city pilot policy plays an important role in inducing the green governance of enterprises. Therefore, policy makers can continue to strengthen the construction of low-carbon city

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pilots by refining pilot experience, building typical cases, actively promoting pilot policy experience, expanding pilot scope and enhancing the implementation efficiency of pilot policy nationwide, which will contribute to the optimization and upgrading of the regional industrial structure at the urban level and will provide experience and reference for the synergistic implementation plan of pollution reduction and carbon reduction.

Social implications – The impact of the low-carbon city pilot policy on enterprise green governance not only exists in two separate paths of urban industrial upgrading and enterprise energy consumption but also exists in a chain transmission path from macro to micro. The authors find that the effect value of each influence path is different, and there is an obvious leading influence path for the role of enterprise green governance. Therefore, in the process of implementing a low-carbon city pilot policy, policies should be designed specifically for different mechanisms. Moreover, complementing and coordinating several paths should be advocated to give full play to the green governance effect of enterprises brought by different paths and to further expand the scope of industries and enterprises where policies play a role.

Originality/value – To the best of the authors' knowledge, for the first time, this paper connects macro mechanisms with micro mechanisms, discovering a macro-to-micro transmission mechanism in the process of low-carbon city pilot policy affecting enterprise green governance. That is, the low-carbon city pilot policy can facilitate industrial structure upgrading, resulting in reduced enterprise energy consumption, ultimately enhancing enterprise green governance.

Keywords Low-carbon city pilot policy, Green governance, Industrial structure upgrading, Energy consumption, Difference-in-differences method

Paper type Research paper

1. Introduction

Environmental pollution and global warming pose significant challenges to the sustainable development of the global economy and deeply impact human survival and development (Jie *et al.*, 2020; Keith *et al.*, 2023). In response, many governments worldwide have established stringent policies for ecological preservation and pollution mitigation (He *et al.*, 2020a). Currently, China remains one of the world's largest carbon emitters (Cai *et al.*, 2020; Pang *et al.*, 2023; Tang *et al.*, 2022). At the United Nations Climate Change Conference in Copenhagen, the Chinese Government pledged to enact robust policies and measures to ensure that its carbon dioxide emissions would peak by 2030 and achieve carbon neutrality by 2060.

As global environmental challenges escalate, the implementation of green governance has become a crucial strategy for promoting sustainable economic development (Dieng and Pesqueux, 2017; Zhang *et al.*, 2022). Green governance involves forging a balance between economic growth and environmental conservation, facilitated by environmental measures and resource efficiency promotion (Ibrahim *et al.*, 2020). Consequently, governments worldwide are adopting stricter policies to address pressing environmental pollution and climate change issues while promoting the growth of a green economy. The role of enterprise green governance in advancing the green economy has gained increasing attention (Abid *et al.*, 2021).

In an effort to effectively curb carbon emissions and promote both green governance and sustainable development, the Chinese Government introduced the "Low-Carbon City Pilot Policy" in 2010 (Qin and Cao, 2022; Tang *et al.*, 2020). China's Low-Carbon City (LCC) policy is largely spearheaded by local governments, resulting in a multilayered, multi-actor policy-making process (Liu and Qin, 2016). The policy mandates pilot areas to estimate and set the total local greenhouse gas emissions, from which they then formulate resource allocation plans. It also requires the establishment of a regional carbon emissions trading regulatory system, the creation of low-carbon development plan (Cheng *et al.*, 2019; Huo *et al.*, 2022).

The low-carbon city pilot policy has garnered significant scholarly interest, leading to the creation of numerous index systems designed to dissect and understand this policy

(Gao *et al.*, 2022; Li *et al.*, 2018; Mabon and Littlecott, 2016; Wang *et al.*, 2021). By using techniques such as questionnaire interviews, scenario analyses and literature metrics, these academics have undertaken extensive research on pilot policies. Nevertheless, while the formulation of an index evaluation system can demonstrate the existence of policy effects, it does not elucidate their nature. Consequently, an analysis and evaluation of the implementation outcomes of the low-carbon city pilot policy is imperative. Researchers have explored these pilot policies from various perspectives, including urban economic development, urban carbon emission reduction and urban ecological efficiency. The body of existing research convincingly shows that the deployment of a low-carbon city pilot policy can boost urban economic growth (Cheng *et al.*, 2019), curtail regional pollution emissions (Feng *et al.*, 2021; Fu *et al.*, 2021; Huo *et al.*, 2022), enhance a city's green total factor productivity (Fu *et al.*, 2021; Zhang *et al.*, 2021a), reduce energy-intensive industry land transfers (Tang *et al.*, 2018a) and foster policy innovation (Tie *et al.*, 2020).

Enterprises, as vital players and contributors to low-carbon city construction, represent major carbon dioxide emitters and are at the forefront of low-carbon product research and development. A micro-level investigation of enterprise development is essential in assessing the impacts of low-carbon city pilot policy. Existing research, focusing on aspects such as enterprise pollution reduction, technological innovation and energy-saving behaviour, has shown that these pilot policies can elevate enterprise green technology innovation Ma *et al.* (2021), enhance production efficiency (Fu *et al.*, 2021) and mitigate pollution emissions (Zhou *et al.*, 2022). Moreover, scholars have analysed the mediating mechanisms through which low-carbon cities influence enterprise development, identifying both industrial structure effects (Cheng *et al.*, 2019) and technology effects (Zhang *et al.*, 2021a) as impactful on enterprise pollution.

Most of the aforementioned studies focus on exploring the impact of low-carbon city pilot policy from the perspective of urban level [such as urban industrial upgrade (Zheng *et al.*, 2021), green governance and development (Zeng *et al.*, 2023b)) or enterprise level (such as corporate green technology innovation (Ma *et al.*, 2021; Xia *et al.*, 2023), total factor productivity (Chen *et al.*, 2021)]. However, these studies often limit their views to a single layer of the city or enterprise, overlooking the mutual influence between cities and enterprises, as well as their combined action paths.

To fill this research gap, this paper firstly selects the SO_2 emission data of industrial enterprises as an indicator of the level of corporate green governance, deeply studying the impact of low-carbon city pilot policy on the level of enterprise green governance. Secondly, it further explores the differences in this impact among different enterprises, industries and regions, thereby providing a more comprehensive and in-depth perspective. Most importantly, this paper proposes and verifies a chained mediation mechanism, constructing a chained mediation model from the low-carbon city pilot policy, to the city's industrial structure, then to the enterprise's energy consumption and ultimately affecting the enterprise green governance. This model elucidates the impact mechanism of enterprise green governance from a macro to micro perspective.

This paper views China's low-carbon city pilot policy as a quasi-natural experiment, with industrial enterprises of a specific size as the focus of our research. We use a difference-in-differences (DID) model to scrutinize the policy's implementation effects, connecting macro-level and micro-level mechanisms to analyse the impact of urban industrial structure upgrading and enterprise energy consumption on enterprise green governance. This approach provides fresh perspectives and data-driven insights for pertinent research.

The remaining sections of this paper are organized as follows: Section 2 presents theoretical analysis and hypotheses; Section 3 describes the research design; Section 4 involves the benchmark regression analysis and robustness tests; Section 5 contains heterogeneity analysis based on the three dimensions; Section 6 concludes the paper and proposes policy implications.

2. Policy background and research hypotheses

2.1 The construction of low-carbon cities in China

In response to climate change and to achieve the strategic “dual carbon” goals, a uniquely Chinese approach to developing low-carbon cities was integrated into the 12th Five-Year Plan. In July 2010, China’s National Development and Reform Commission launched the Notice on the Pilot Work of Low-Carbon Provinces and Cities, marking the initiation of low-carbon city pilots in five provinces and eight cities. Throughout the “Twelfth Five-Year Plan” period, driven by these pilot policies, China experienced an 18.2% reduction in energy consumption per unit GDP and a 2.6% increase in the proportion of non-fossil fuel consumption. Between 2010 and 2011, the CO_2 emissions per unit GDP in the pilot cities decreased by 88.9% compared to other cities within the same province. For instance, the per unit GDP CO_2 emissions in Jingdezhen, Zunyi, Urumqi and Wuhan were 24.47%, 20.43%, 19.44% and 19.12%, respectively, lower than their provincial averages. Encouraged by the positive outcomes of the initial pilot policies, the National Development and Reform Commission further broadened the low-carbon city pilot initiative to include county-level units in 2012 and 2017. The distribution of China’s low-carbon city pilot policy is depicted in Figure 1.

To fully present the development process of the low-carbon city pilot policy, this paper conducts in-depth research on public policy documents and official announcements, collecting relevant information about all three batches of pilot cities that have implemented

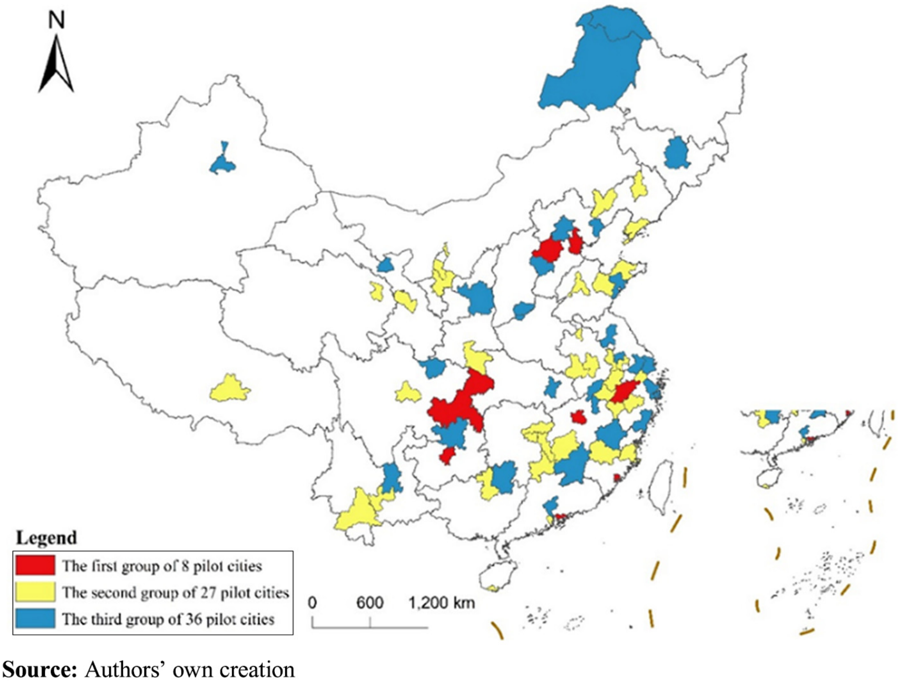

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Figure 1. Distribution of pilot policies for three batches of low-carbon cities in China

this policy, including the time and location of policy implementation, among other details. In reference to the latest administrative division data provided by the National Bureau of Statistics of China, using Geographic Information System (GIS) software, demonstration cities from different batches are marked in different colours. A distribution map of China's low-carbon city pilot policy is created, as shown in Figure 1.

2.2 Research hypotheses

When evaluating the impact of low-carbon city pilot policy, two key questions arise:

Q1. Can these policies enhance the green governance within enterprises?

Q2. What mechanisms drive this impact?

To probe these queries, this paper examines the influence of low-carbon city pilot policy on enterprise green governance, dissecting four critical aspects.

Firstly, a low-carbon city pilot policy can harmonize diverse environmental regulatory tools such as market incentives, governmental directives and fiscal, financial and industrial strategies (Qi *et al.*, 2021), thereby reflecting the industry characteristics and the interplay of various policies (Lu *et al.*, 2020). Regarding industry characteristics, high energy-consuming sectors like the electrical and petrochemical industries face emission standards in the low-carbon pilot policy that effectively manage urban pollutant emissions (Liu *et al.*, 2022). Moreover, these standards enhance corporate motivation to reduce pollution, fostering sustainable pollution governance. Consequently, enterprises transition towards green, economical and efficient energy use, thereby realizing the objective of green governance. From the policy interplay standpoint, the pilot policy mitigates enterprise financial constraints through governmental environmental regulation-driven financial support (Ma *et al.*, 2021). It also facilitates automatic regulation of environmental resources via market-driven environmental regulation mechanisms, such as pollutant discharge fees. This boosts resource utilization, production efficiency and economic productivity within enterprises, spurring their drive towards green governance behaviours and ultimately achieving enterprise green governance. Therefore, this paper proposes the following hypothesis:

H1. Low-carbon city pilot policy can enhance the green governance capabilities of enterprises.

Secondly, low-carbon city pilot policy influences urban industrial structures at both macro and micro levels. At a macro level, these policies represent the government's use of market mechanisms to stimulate growth in emerging industries characterized by low energy consumption and emissions. The government capitalizes on local industrial advantages to foster the development of low-carbon sectors. For instance, Huo *et al.* (2022) posit that the establishment of low-carbon cities can facilitate the transition from traditional agriculture, industry and services to ecological agriculture, low-carbon industry and modern services, respectively. On the micro level, these policies bolster the government's macro-control over urban pollution reduction, encourage region-specific low-carbon industrial development and foster cleaner production practices among enterprises (Chen *et al.*, 2020; Fu *et al.*, 2021). Influenced by local government environmental measures, such as pollution charges and environmental tax collection, enterprises characterized by high energy consumption and emissions may exit the market, relocate or adjust their production structures to align with policy requirements (Cheng *et al.*, 2019). Enterprises that choose to exit or relocate contribute to a reduction in local pollution levels, while those adjusting their production structures improve their green governance capabilities throughout the development process. Therefore, we propose the following hypothesis:

H2. Low-carbon city pilot policy can enhance the green governance capabilities of enterprises through industrial structure upgrading.

Thirdly, low-carbon city pilot policy impacts enterprise energy consumption. As an all-encompassing environmental regulation policy designed to mitigate environmental pollution, the enactment of a low-carbon city pilot policy inevitably influences the consumption of coal, petroleum and other energy sources during industrial enterprises' operations. For instance, Zhou *et al.* (2022) found that the establishment of low-carbon cities considerably diminishes enterprise coal consumption and dependency. Moreover, under the continued influence of policy effects, enterprises may heighten their energy input to compensate for anticipated losses, leading to more severe pollution in the short term and subsequently creating a "green paradox" (Folster and Nystrom, 2010; Smulders *et al.*, 2012). This paradox can stimulate enterprises to expedite their green transformation, decrease consumption of high-polluting energy sources, enhance overall energy efficiency (Xiang *et al.*, 2022) and establish a virtuous cycle to augment green governance (He *et al.*, 2020b). Therefore, we propose the following hypothesis:

H3. Low-carbon city pilot policy can enhance the green governance capabilities of enterprises by influencing their energy consumption.

Fourthly, low-carbon city pilot policy impacts both industrial structure upgrading and enterprise energy consumption. A primary objective of low-carbon city pilot policy is to guide the formation of a low-carbon environmental industrial system. Acting as an external policy influence, these policies have altered the urban industrial development environment by limiting high-pollution industries' growth, fostering emerging low-carbon environmental protection industries and promoting industry-wide resource reallocation. By stimulating green low-carbon industrial transformation, adjusting the industrial structure and encouraging the development of emerging industries, low-carbon city pilot policy fosters the optimization and upgrading of urban industrial structures (Cheng *et al.*, 2019). Additionally, these structural optimizations and upgrades can alter the industry's overall energy structure and efficiency through factor flows and resource optimization (Lin and Raza, 2020; Tang *et al.*, 2018b). They can also enhance enterprises' technological innovation levels and technology transformation capabilities (Zhang *et al.*, 2021b). Over the long term, these transformations could spur the substitution of traditional energy and capital elements, thereby reducing enterprises' energy consumption and augmenting their green governance capabilities. Therefore, we propose the following hypothesis:

H4. Low-carbon city pilot policy affects the energy consumption of enterprises by upgrading the industrial structure, thereby impacting the green governance capabilities of enterprises.

3. Research design

3.1 Data source and processing

This study uses foundational data sourced from the China Industrial Enterprise Database and the China Enterprise Pollution Database. However, the industrial enterprise data only extends up to 2014, as the subsequent years' data have not been released to maintain industry confidentiality. Consequently, this study sets 2012 as the reference point for policy implementation and gathers data from the five-year period preceding policy implementation, specifically from 2007 to 2013. Additionally, due to a significant lack of enterprise-related data in the industrial enterprises database for 2010, data from this year is omitted from our analysis.

Prior to data regression analysis, we merged two microenterprise databases (Brandt *et al.*, 2012; Xiao *et al.*, 2022) to procure unbalanced panel data encompassing economic and environmental information. We then selected industrial enterprises above the designated size for our study, processing the matched industrial enterprise data as follows: removed enterprises with negative or zero emissions of sulfur dioxide, chemical oxygen demand, industrial waste gas, industrial wastewater, smoke and dust; excluded enterprises with missing, negative and abnormal key variables such as total assets, gross industrial output value and fixed assets, as these did not comply with general accounting standards; deleted enterprises with fewer than eight employees. Finally, by merging enterprise data with the city-level data from the prefecture-level city where the enterprise is located, we obtained panel data for industrial enterprises above a designated size in 290 prefecture-level cities from 2007 to 2013.

3.2 Model settings

To ascertain whether low-carbon city pilot policy can enhance enterprise green governance, this study employs the DID method (Fu *et al.*, 2021; Liu *et al.*, 2022; Song *et al.*, 2020). This method partitions the subjects into a treatment group (areas where policies have been implemented) and a control group (areas without policy implementation), and then analyses the differences in time trends before and after policy implementation. It further compares the distinctions between the treatment and control groups based on whether the policy has been implemented or not. In doing so, we can mitigate unobservable factors that alter over time, thereby identifying the net effect of policy implementation.

Given the initial limited implementation of the first batch of low-carbon city pilots and the simultaneous intervention of two batches, it was challenging to discern the policy impact of the first batch of pilot cities within a short timeframe. For the purpose of this study, two batches of provincial and prefecture-level cities, included in the low-carbon city pilot scope in 2010 and 2012, are designated as treatment groups, while the remaining provincial and prefecture-level cities serve as control groups. From the perspective of enterprise green governance, we conduct a quantitative evaluation of the low-carbon city pilot policy. The specific model (1) configurations are as follows:

$$\ln SO_{2i,t} = \beta_0 + \beta_1 Treat_i \times Period_t + \rho Control_{i,t} + V_i + V_t + \varepsilon_{i,t} \quad (1)$$

In Model (1), $\ln SO_{2i,t}$ represents the SO_2 emission intensity of industrial enterprise i in year t. $Treat_i$ denotes the dummy variable for the low-carbon pilot area. If a city belongs to the first two batches of pilot areas, its value is assigned as 1; otherwise, the value is set to 0. $Period_t$ indicates the dummy variable for the pre- and post-policy pilot year; during the low-carbon city pilot period (2012 and beyond), the value is 1, whereas, for the non-pilot period, the value is 0. $Control_{i,t}$ refers to the control variable matrix at both city and industrial enterprise levels. V_i and V_t represent individual and time fixed effects, respectively, and $\varepsilon_{i,t}$ r signifies the residual item.

3.3 Variable selection and measurement

3.3.1 Dependent variable. The dependent variable of this paper pertains to the green governance of industrial enterprises. While numerous indicators are available for use, the "five waste" index is frequently used. However, to ensure comprehensive and accessible data from industrial enterprises, this paper opts to measure green governance through sulfur dioxide emissions (lnSO_2) based on pollution data from Chinese industrial enterprises (Xiao *et al.*, 2022; Zhang *et al.*, 2022).

3.3.2 Independent variable. This study uses the designation of a city as a low-carbon pilot city as the policy grouping's dummy variable, while the policy implementation timeframe is considered the time grouping's dummy variable. The product of these two variables serves as the main independent variable. For the selection of low-carbon cities, we have included both the low-carbon cities and their respective provinces from the low-carbon city pilot list (Feng *et al.*, 2021). To accurately represent policy attributes, we focus our research solely on prefecture-level cities listed as pilot cities, excluding those with missing data.

3.3.3 Mediation variable. This study selects the upgrading of the urban industrial structure (*ais*) as the mediating variable M1 (Jiang *et al.*, 2020; Liu, 2022), which is represented by the industrial structure hierarchy coefficient. In essence, this tracks the evolution process of the three sectors at a quantitative level, predicated upon the relative changes in their respective share proportions. The specific formula for calculation is as follows:

$$\mathrm{M1} = ais_{i,t} = \sum\nolimits_{1}^{3} y_{i,m,t} \times m, m = 1, 2, 3 \tag{2}$$

In equation (2), $y_{i,m,t}$ denotes the proportion of industry m in region i to GDP in period t, effectively representing the trajectory of regional industrial development as it transitions from primary to secondary and tertiary sectors. For this study, we use the logarithm of total enterprise coal consumption (ln*carbon*) from the matched data set of industrial enterprises and pollutants as a mediating variable M2, which serves as a measure of energy utilization within enterprises (Zhang *et al.*, 2021b).

3.3.4 Control variable. This paper includes a set of enterprise economic characteristics and city-level influencing factors as control variables to mitigate the potential impact of missing variables on the regression test results. At the enterprise level, these variables encompass enterprise size (ln*Size*), enterprise age (ln*Age*), enterprise asset liability ratio (*Lev*) and enterprise management (*Manage*) (Ma *et al.*, 2021; Zhang *et al.*, 2020; Zhou *et al.*, 2021b). At the urban level, the variables comprise GDP per capita (ln*pgdp*), urbanization level (*Urban*) and population density (ln*pop*) (Fan *et al.*, 2021; Wang *et al.*, 2022). Descriptive statistics for these variables are presented in Table 1.

Variables	*N*	Mean	SD	Min	Max
ln*pgdp*	48,051	10.17	0.731	4.595	13.06
ln*pop*	51,312	5.800	0.838	1.573	7.869
Urban	51,415	0.773	0.340	0	3.594
ln*Age*	52,531	2.38	0.567	0	3.66
ln*Size*	52,521	11.86	1.520	6.052	19.28
Lev	52,521	0.574	0.315	−0.581	19.30
Manage	52,519	0.0535	0.102	−0.172	17.34
did	52,531	0.144	0.351	0	1

Source: Authors' own creation

Table 1. Variable definitions and descriptive statistics results

4. Empirical analysis

4.1 Benchmark regression

The benchmark regression results of this study are presented in Table 2. The estimated impacts of the low-carbon city pilot policy on the SO_2 emission intensity from industrial firms, both with and without control variables, are exhibited in Columns (1) and (2), respectively. Notably, the DID coefficients in the table show a significant negative value (−0.158 and −0.272, respectively), substantiating that the implementation of the low-carbon city pilot policy has meaningfully diminished the SO_2 emission intensity within industrial enterprises in the pilot area. *H1* is passed, the low-carbon city pilot policy has fostered the progression of green governance within these enterprises.

4.2 Robustness tests

4.2.1 Parallel trend test. The DID model necessitates the fulfillment of the parallel trend assumption by both the treatment and control groups to ensure unbiased estimation. Specifically, prior to the execution of the low-carbon city pilot policy, the SO_2 emission intensity from industrial firms in the pilot cities is expected to follow a similar temporal trend as the emission intensity of the non-pilot cities. However, any deviation from the parallel trend between the treatment and control groups post-policy implementation implies a shift in the trend of green governance within firms located in pilot cities, as compared to non-pilot cities. To validate this assumption, this paper employs the event study methodology for testing the parallel trend, as proposed by Sun *et al.* (2020). The model is as follows:

$$\ln SO_{2i,t} = \sigma + \sum_{t=-5}^{2} \theta_t D_{i,t} + \rho Control_{i,t} + V_i + V_t + \varepsilon_{i,t} \tag{3}$$

In the Model (3), $D_{i,t}$ represents a binary variable. It holds a value of 1 if the city where enterprise i resides has enforced the low-carbon city pilot in the year t, and 0 otherwise. For the purpose of this study, the pilot year of the low-carbon cities is considered as the benchmark year. The investigation involves analysing whether the dynamic effect coefficient θ_t of the policy significantly deviates from 0, thereby determining the fulfillment

Table 2. Benchmark regression results and robustness test results

Variables	(1) $\ln SO_2$	(2) $\ln SO_2$	(3) $\ln SO_2$	(4) $\ln Water$
did	−0.158*** (−5.19)	−0.272*** (−8.36)	−0.189*** (−5.44)	−0.160** (−2.23)
ln*pgdp*		0.056*** (3.05)	0.044** (2.41)	−0.177*** (−4.10)
ln*pop*		0.025** (2.12)	0.023* (1.92)	−0.007 (−0.25)
Urban		−0.234*** (−7.89)	−0.246*** (−8.26)	−0.377*** (−5.08)
ln*Age*		−0.002** (−2.18)	−0.002** (−2.05)	0.008*** (2.72)
ln*Size*		0.444*** (59.40)	0.447*** (60.76)	0.586*** (38.27)
Lev		0.460*** (9.04)	0.500*** (9.47)	−0.073 (−1.08)
Manage		−1.159* (−1.91)	−2.730*** (−10.53)	1.371 (1.51)
_cons	10.268*** (1063.46)	4.263*** (24.22)	4.386*** (24.95)	3.369*** (8.12)
Time fixed effect	YES	YES	YES	YES
Observations	52,531	46,891	46,889	46,891
R^2	0.054	0.152	0.150	0.142

Notes: Robust t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source: Authors' own creation

of the parallel trend assumption. The outcomes of this analysis are depicted in the subsequent Figure 2.

As illustrated in the Figure 2, prior to the implementation of the low-carbon city pilot policy, the 95% confidence interval of the dynamic effect coefficient θ_t encompasses 0. This suggests no significant discrepancy between the SO_2 emission intensity of firms in low-carbon pilot areas and non-low-carbon cities, thereby satisfying the parallel trend assumption. From the onset of the policy implementation's first year, the 95% confidence interval of θ_t no longer includes 0. This denotes that the low-carbon city pilot policy has contributed significantly toward reducing the SO_2 emission intensity of firms. Given the coefficient's value, a declining trend becomes apparent, indicating a consistent reduction in the SO_2 emission intensity of firms as the policy continues to take effect over time. The foregoing analysis substantiates the parallel trend assumption of the DID model used in this study.

4.2.2 Propensity Score Matching-Difference-in-differences test. Acknowledging that the initial conditions of pilot and non-pilot cities may not be identical, this study introduces the propensity score matching-DID (PSM-DID) method to mitigate the sample selection bias resulting from varying initial conditions across treatment and control groups. This method also helps alleviate endogeneity problems engendered by sample selection bias. A robustness test is subsequently performed. The nearest neighbor matching method is used, using samples within the common support range for the DID estimation post-PSM. The outcomes are presented in Column (3) of Table 2. No significant alterations are observed in the coefficients and symbols, thereby affirming the robustness of the conclusion.

4.2.3 Placebo test. The placebo test serves as a mechanism to validate whether there are any unobservable factors that might interfere with the DID estimation. In this context, this study uses the placebo method to confirm the robustness of Column (2) of the benchmark regression results. The specific procedure involves generating a random list of low-carbon city pilot cities, equal in number to the actual count of such cities. This list is then used to execute the DID regression on Model (1) for 800 iterations to enhance test reliability. The subsequent Figure 3 presents the results of the placebo test concerning the impact of the low-carbon city pilot on the SO_2 emission intensity of enterprises. The regression coefficient of the low-carbon city pilot on enterprise's SO_2 emission intensity is predominantly centered around 0, and the regression coefficient (−0.272) of Column (2) of benchmark regression surpasses

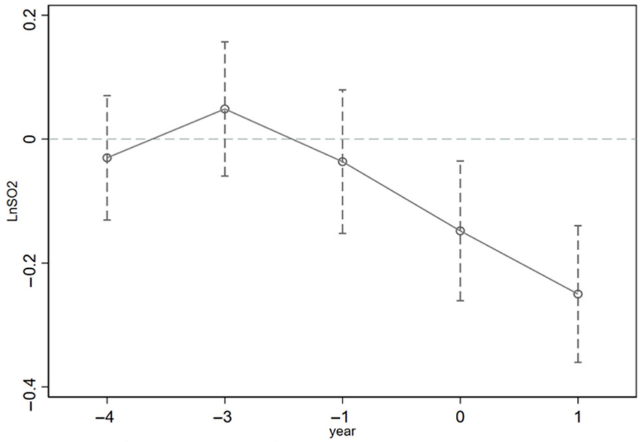

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Figure 2.
Parallel trend test

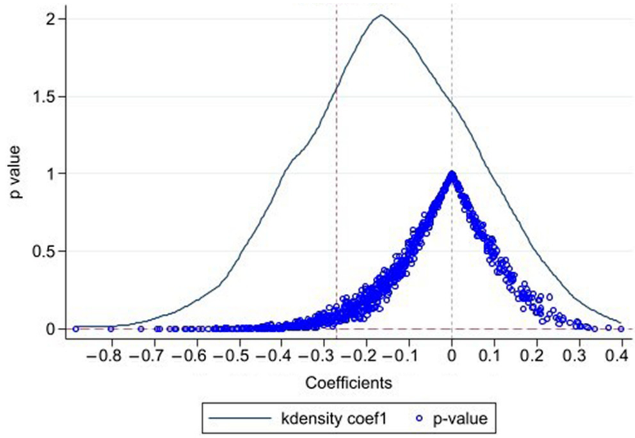

Figure 3.
Placebo test

Source: Authors' own creation

99% of the 800 coefficient estimates. Consequently, we can eliminate the likelihood that the regression outcome of Column (2) of benchmark regression is influenced by unobservable factors.

4.2.4 Other robustness tests

4.2.4.1 Replace the dependent variable. In recognition of the potential impact of different dependent variables on model estimation results, this study substitutes sulfur dioxide emissions (lnSO_2) with the logarithm of wastewater discharge from industrial enterprises (ln*Water*). It uses ln*Water* as the dependent variable to gauge the green governance of enterprises and further conduct regression analysis. This approach is taken to bolster the persuasiveness of the conclusion and confirm the robustness of the benchmark regression. The regression outcomes are presented in Column (4) of Table 2. At a 5% significance level, the pilot policy for low-carbon cities resulted in a reduction of wastewater discharge (−0.10) from industrial enterprises in the pilot area. This effect indicates a positive influence on the green governance of enterprises and aligns with the benchmark regression results.

4.2.4.2 Eliminate other policy interference. To mitigate potential interference from other pilot policies implemented concurrently, it was identified through document collection and analysis that the emission trading pilot policy could influence enterprise green governance. Consequently, this study incorporated the grouping variable policy and the cross-term of the time dummy variable for the policy pilot year into the benchmark regression model. This adjustment allows for controlling the potential interference from the pilot emission trading policy in the estimated outcomes. The result remains consistent in Column (1) of Table 2, implying that the empirical findings maintain their validity even after accounting for other policies that might affect the green governance of enterprises. This consistency demonstrates the robustness of the benchmark regression results.

5. Mechanism analysis

5.1 Mediation role of industrial structure upgrading and enterprise energy consumption

5.1.1 Industrial structure upgrading. From the perspective of industrial structure upgrading at the urban level, this paper constructs the following mediation model (4):

$$\ln SO_{2i,t} = \theta_0 + \theta_1 Treat_i \times Period_t + \theta_3 ais_{i,t} + \theta_4 Control_{i,t} + \varepsilon_{i,t} \quad (4)$$

The regression outcomes are presented in Table 3. In Model (1), we observe that the direct effect of DID on enterprise sulfur dioxide emissions is −0.451 before the inclusion of industrial structure upgrading mediation, significant at the 1% level. In Model (4), the direct effect value of DID on urban industrial structure upgrading is 0.059, also significant at the 1% level; the impact value of industrial structure upgrading on sulfur dioxide emissions from enterprises is −0.642, which is significant at the 1% level; after introducing the mediation effect, the direct effect of DID on sulfur dioxide emissions from enterprises is −0.411, again significant at the 1% level. These findings demonstrate that the low-carbon city pilot policy can enhance enterprise green governance by influencing industrial structure upgrading. Therefore, *H2* is successfully validated.

5.1.2 Enterprise energy consumption. From the perspective of enterprise energy consumption, this paper constructs an mediation model (5):

$$\ln SO_{2i,t} = \partial_0 + \partial_1 Treat_i \times Period_t + \partial_3 \ln carbon_{i,t} + \partial_4 Control_{i,t} + \varepsilon_{i,t} \quad (5)$$

The regression outcomes are presented in Table 4. It can be found that in model (1), the direct effect of DID on the sulfur dioxide emissions of enterprises is −0.451 before the addition of industrial structure upgrading intermediaries, and is significant at the 1% level. In Model (5), the direct impact of DID on enterprise energy consumption is −2.400, significant at the 1% level; the effect value of enterprise energy consumption on sulfur dioxide emissions is 0.174, also significant at the 1% level; upon the inclusion of the mediation effect, the direct impact on enterprises' sulfur dioxide emissions is −0.033, which is not statistically significant. This result indicates a substantial full mediation effect of enterprise energy consumption in the promotional process of the low-carbon city pilot policy on enterprise green governance. Therefore, *H3* is successfully validated.

5.2 The chain mediation role of industrial structure upgrading and enterprise energy consumption

As discussed previously, this research has affirmed that the low-carbon city pilot policy can enhance enterprise green governance through two pathways: urban industrial structure upgrading and enterprise energy consumption. However, industrial structure upgrading operates at a city level, while energy consumption pertains to the enterprise level. Is there a transmission mechanism bridging these two levels of impact? Therefore, we construct a

Variables	(1)
$\ln SO_2$	
did	−0.104*** (−2.80)
Emission trading pilot policy	YES
Control	YES
_cons	3.380*** (17.56)
Time fixed effect	YES
Observations	46,891
R^2	0.148

Notes: Robust *t*-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source: Authors' own creation

Table 3. Robustness test (excluding other policy impacts)

Table 4.
Test of the mediation effect between industrial structure upgrading and enterprise energy consumption

Variables	(1) Model (1) lnSO_2	(2) Model (4) M1	(3) Model (4) lnSO_2	(4) Model (5) M2	(5) Model (5) lnSO_2
did	−0.451*** (−16.77)	0.059*** (19.87)	−0.411*** (−15.27)	−2.400*** (−52.18)	−0.033 (−1.25)
M1			−0.642*** (−15.49)		
M2					0.174*** (67.55)
Control	YES	YES	YES	YES	YES
_cons	4.498*** (26.52)	2.403*** (127.10)	6.027*** (30.68)	17.108*** (58.92)	1.522*** (9.07)
Observations	46,891	46,800	46,800	46,891	46,891
R^2	0.108	0.032	0.113	0.367	0.187

Notes: Robust *t*-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source: Authors' own creation

chain mediation model (4), founded on Model (4) and Model (6), to investigate this transmission mechanism:

$$\ln SO_{2i,t} = \varnothing_0 + \varnothing_1 Treat_i \times Period_t + \varnothing_3 ais_{i,t} + \varnothing_4 \ln carbon_{i,t} + \varnothing_5 Control_{i,t} + \varepsilon_{i,t} \quad (6)$$

The regression outcomes are presented in Table 5. In the chain mediation model, we find that the direct impact of the low-carbon city pilot policy on enterprise green governance through urban industrial structure upgrading is −0.035, and the direct impact of enterprise energy consumption on enterprise green governance is −0.410. The chain mediation effect value for industrial structure upgrading and enterprise energy consumption is −0.004. However, the direct impact of the low-carbon city pilot policy on enterprise green governance is not significant, suggesting that industrial structure upgrading and enterprise energy consumption fully mediate the influence of the low-carbon city pilot policy on enterprise green governance. Therefore, *H4* is successfully validated.

6. Heterogeneity analysis

6.1 Regional heterogeneity

Given the disparities in economic development, technological innovation and industrial structure among the eastern, central and western regions, the low-carbon city pilot policy may exert varied impacts on enterprise green governance across these different jurisdictions. Accordingly, this study categorizes the samples from Beijing, Tianjin, Hebei, Zhejiang, Jiangsu, Fujian, Shandong, Guangdong, Liaoning and Hainan as the eastern regions. The samples from Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Henan, Hubei, Hunan and Jiangxi are classified as the central regions. Lastly, samples from the remaining provinces are allocated to the western regions. The empirical findings are presented in Table 6. The low-carbon city pilot policy in the eastern regions has notably enhanced the green governance of industrial enterprises within its jurisdiction. However, in the samples from the central and western regions, the impact of the low-carbon city pilot policy is not statistically significant.

6.2 Enterprise heterogeneity

Taking into account that the ownership structure of enterprises may influence the effects of the pilot policy, this paper obtains the information about the actual controller nature of enterprises from the CSMAR database, defining enterprises with the actual controller nature

Path	Effect value
Pilot policy of low-carbon cities → Enterprise green governance	−0.000 (−0.02)
Pilot policy of low-carbon cities → Industrial structure upgrading → Enterprise green governance	−0.035*** (−10.27)
Pilot policy of low-carbon cities → Enterprise energy consumption → Enterprise green governance	−0.410*** (−56.19)
Pilot policy of low-carbon cities → Industrial structure upgrading → Enterprise energy consumption → Enterprise green governance	−0.004*** (−5.09)
Overall chain mediation	−0.449*** (−15.53)
Observations	46,800

Notes: Robust *t*-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source: Authors' own creation

Table 5. Test results of chain mediation effect

as “state-owned enterprises”, “administrative institutions and public institutions”, “central institutions” and “local institutions” as state-owned enterprises, and other enterprises as non-state-owned enterprises. These state-owned enterprises information databases are matched with the pollution emission data of Chinese industrial enterprises to perform heterogeneity analysis of state-owned and non-state-owned enterprises. The empirical findings are presented in Columns (1) and (2) of Tables 7. In the sample of state-owned enterprises, the estimated coefficient is not statistically significant. Conversely, the estimated coefficient of non-state-owned enterprises is significant, suggesting that non-state-owned enterprises exhibit a more pronounced tendency towards green governance under the low-carbon city pilot policy.

In addition to enterprise ownership, this study considers enterprise size as another factor influencing the policy impact. In this paper, drawing from the study by Li and Zheng (2016), the median of total assets of listed companies in China provided by Cathay Securities is used as the standard to classify large-scale and small-scale enterprises. If a company’s total assets exceed the median, it is defined as a large-scale enterprises; conversely, if the total assets are below the median, it is considered a small-scale enterprises. The empirical regression results are displayed in Columns (3) and (4) of Table 7. The findings indicate that compared to small-scale enterprises, large-scale enterprises exhibit a more pronounced effect on green governance under the low-carbon city pilot policy.

6.3 Industry heterogeneity

To determine whether the effect of the low-carbon city pilot policy on the green governance of enterprises varies across industry technologies, this study, based on the “National

Table 6. Regional heterogeneity test results

Variables	(1) Eastern regions	(2) Central regions	(3) Western regions
did	−0.326*** (−8.48)	−0.070 (−0.89)	−0.147 (−1.52)
Control	YES	YES	YES
_cons	3.489*** (14.29)	4.020*** (13.77)	7.525*** (13.12)
Observations	28,847	10,917	7,127
R^2	0.146	0.203	0.118

Notes: Robust *t*-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source: Authors’ own creation

Table 7. Enterprise heterogeneity test results

Variables	(1) State-owned enterprises	(2) Non-state-owned enterprises	(3) Large-scale enterprises	(4) Small-scale enterprises
did	−0.254 (−0.89)	−0.445*** (−14.35)	−0.576*** (−14.45)	−0.209*** (−6.01)
Control	YES	YES	YES	YES
_cons	−2.716* (−1.72)	4.676*** (27.29)	2.399*** (8.13)	5.974*** (24.30)
Observations	592	46,501	23,565	23,528
R^2	0.232	0.103	0.109	0.023

Notes: Robust *t*-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source: Authors’ own creation

Economic Industry Classification", refers to the Organization for Economic Cooperation and Development classification standards for high technology industries (Galindo-Rueda and Verger, 2016), dividing different industries into high technology and low technology categories. High technology industries comprise communication equipment, computer and other electronic equipment manufacturing, special equipment manufacturing, transportation equipment manufacturing, pharmaceutical manufacturing, chemical fibre manufacturing, chemical raw materials and chemical products manufacturing, electrical machinery and equipment manufacturing and instrument manufacturing. All other industries are categorized as medium and low technology industries. The grouped regression results shown in Column (1) and Column (2) of Table 8 demonstrate that the low-carbon city pilot policy reduces the pollution emission intensity of both high technology and medium and low technology industries. However, due to their higher level of technological innovation and superior green production efficiency, high technology industries exhibit more pronounced green governance.

Moreover, industries that are a significant source of pollution often fall under stricter environmental oversight by government authorities due to public concern, which may result in a reduction of pollutant emissions and consequently improved green governance. To further examine the industrial heterogeneity of pollution levels, referring to the heavily polluted industries stipulated by the Ministry of Environmental Protection of China, and drawing from the study by Zhou *et al.* (2021a), this study classifies certain industries as heavy pollution industries, including coal mining, petroleum processing, gold mining, ferrous metal mining and processing, textile industry, paper making, chemical raw materials and chemical products manufacturing, chemical fibre manufacturing, non-ferrous metal manufacturing, gold processing and electrical production. Meanwhile, agricultural and sideline food processing, food manufacturing, beverage manufacturing, printing, communication equipment, computer and other electronic equipment manufacturing industries are classified as medium and light pollution industries. The results are displayed in Columns (3) and (4) of Table 8. The estimated coefficients of DID for the samples from heavy, medium and light pollution industries are −0.212 and −0.339, respectively, and both are statistically significant. These results indicate that the low-carbon city pilot policy can encourage enterprises in heavy pollution industries to reduce pollution emission intensity. However, the emission intensity of medium and light pollution industries has decreased more significantly. This might be because heavy pollution enterprises are compelled to reinforce pollution control through measures like investing more in environmental protection elements and elevating the level of green technological innovation. Therefore, in comparison, the

Variables	(1) High technology industries	(2) Medium and low technology industries	(3) Heavy pollution industries	(4) Medium and light pollution industries
did	−0.331*** (−4.88)	−0.251*** (−7.08)	−0.212*** (−5.88)	−0.339*** (−6.62)
Control	YES	YES	YES	YES
_cons	5.071*** (15.02)	3.912*** (19.70)	3.284*** (17.00)	7.334*** (25.71)
Observations	12,655	34,236	28,729	18,161
R^2	0.171	0.177	0.251	0.109

Notes: Robust *t*-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source: Authors' own creation

Table 8. Industry heterogeneity test results

emission intensity of medium and light pollution industries has experienced a greater decrease.

7. Conclusions and policy implications

7.1 Research conclusion

The implementation of low-carbon city pilot policy has a significant impact on enhancing the level of enterprise green governance. This will, while dealing with resource and environmental pressures, promote the construction of a harmonious ecological civilization (Qiu *et al.*, 2021). The importance of this plan as a core guideline for solving carbon emissions issues is self-evident. This paper uses the DID method to conduct multi-dimensional empirical tests on the policy effects of low-carbon city pilots, based on panel data of China's large-scale industrial enterprises from 2007 to 2013. The results are as follows:

Firstly, the baseline regression results indicate that the low-carbon city pilot policy can enhance the level of enterprise green governance. This conclusion still holds after a series of robustness tests, including parallel trend tests, PSM-DID, placebo tests, substitution of dependent variables and exclusion of other policy interferences. Secondly, the mechanism analysis in this paper suggests that the low-carbon city pilot policy can promote enterprise green governance by accelerating urban industrial structure upgrading or reducing enterprise energy consumption. There also exists a transmission mechanism from macro to micro in this process, i.e. the low-carbon city pilot policy promotes enterprise green governance by reducing enterprise energy consumption through promoting urban industrial structure upgrading.

In addition, further heterogeneity findings reveal that at the regional level, the effect of the low-carbon city pilot policy is more significant in the eastern region compared to the central and western regions. At the enterprise level, the pollution reduction policy effect is more pronounced for non-state-owned enterprises compared to state-owned enterprises; large-scale enterprises are more noticeably impacted by this policy, leading to more efficient green governance. At the industry level, compared to low technology industries, the promotion of enterprise green governance is more significant in high-tech industries; simultaneously, the policy's promotion of enterprise green governance is more significant in medium and light pollution industries, whereas the promotion effect is limited in high pollution industries.

7.2 Policy implications

Based on the research conclusions obtained, to promote the effective implementation of the low-carbon city pilot policy and facilitate high-quality development of enterprises, we propose the following policy recommendations:

Enterprises should pay attention to and actively respond to the relevant policies of low-carbon pilot cities, elevating low-carbon policy to strategic importance. During the policy implementation process, they should actively understand the fiscal incentive policies within the pilot areas to compensate for the expenditure in energy conservation, emission reduction and green investment (Li *et al.*, 2022). Simultaneously, enterprises need to seize policy opportunities, phase out outdated technologies, increase R&D investment to enhance green innovation performance (Ma *et al.*, 2021), develop plans for green sustainable development and actively fulfill their social responsibilities.

Industrial structure upgrading and enterprise energy consumption are key paths to promote the enhancement of enterprise green governance. Therefore, local governments should effectively supervise and guide pilot cities, pay attention to the roles of these two key factors, provide enterprises with a higher quality green innovation environment, stimulate their innovation potential and thus achieve low-carbon development (Zhu, 2022). Moreover, local governments should advocate for the complementarity and coordination of various paths, so as to fully exploit the effects of each path on enterprise green governance, and further broaden the scope of industries and enterprises influenced by the policy.

Promote the low-carbon transformation of various industries in a categorized and regionalized manner. low-carbon city pilot policy should pay close attention to the central and western regions with relatively lagging economic development, as well as traditional industries, high-pollution, high-carbon enterprises (Yang *et al.*, 2023). Past experiences of low-carbon city pilots and empirical results have shown that these regions and industries need to be a primary focus. Therefore, the implementation of low-carbon pilot city policies should avoid the "one size fits all" approach, but should timely and effectively adjust policies according to specific circumstances.

7.3 Limitations

In this study, the reliability and stability of the results are beyond dispute. However, due to the limitations of data accessibility, we can only verify the short-term effects of the policy, thereby reducing the accuracy of policy predictions. At the same time, considering that the research on the low-carbon city pilot policy inevitably involves interference from other policy factors, which are difficult to include entirely in the research model, this constitutes an unavoidable limitation of policy effect research. In addition, given that the low-carbon city pilot policy is still in progress, as more data become available, we can continue to track and analyse this policy, and further extend the research dimensions. This approach may provide a more comprehensive understanding of the policy and its impacts over the long term, across various sectors and under diverse conditions.

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