Impact of the "Low-Carbon City Pilot" Policy on Energy Intensity Based on the Empirical Evidence of Chinese Cities

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Reducing energy intensity is conducive to the sustainable use of non-renewable fossil energy, and is also one of the main strategies to deal with climate change and environmental degradation. The effect of national macro-level factors on energy intensity has been basically confirmed, but the effect of regional low-carbon policy remains to be investigated. Based on this, our analysis exploits China's "low-carbon city pilot" policy as a quasi-natural experiment and conducts the difference-in-difference resign. We collect the panel data of 271 cities in China from 2006 to 2016. The empirical results show that: first, the low-carbon city pilot policy can effectively reduce the energy intensity. Second, there exist heterogeneous effects on energy intensity among different cities, and the inhibition effects in eastern cities, high economic development cites, and non-old industrial-base cities are more significant. Third, the policy mainly affects regional energy intensity through technological innovation rather than industrial structure optimization mechanism.

Keywords: the low-carbon city pilot policy, energy intensity, cities, China, difference-in-difference

INTRODUCTION

Energy intensity relates to the sustainable utilization of non-renewable resources such as fossil energy. Reducing energy intensity is also one of the main strategies to deal with current problems of climate change and environmental degradation. As the main habitat of human production and life, cities are also the main places of carbon emissions. According to the BP statistical review of world energy in 2020, China has become the largest energy consumer, whose energy consumption accounts for 24.5% of the total global consumption in 2019, but its energy efficiency is still low, though always improving(Liang et al., 2020). Moreover, China's energy intensity is unbalanced among different regions that the energy intensity in the eastern coastal areas is far lower than that in the central and western regions (Jiang et al., 2017). Although Chinese policy makers have always attached great importance to reducing energy intensity, China's energy intensity has been increased in the process of rapid urbanization (Yan, 2015).

Most scholars mainly study the determinants of energy intensity from the national macro level, which includes factors affecting energy demand (per capita income, green technology innovation, etc.), energy supply (energy tax, etc.) and the energy price factor. For example, Filipović et al. (2015) and Samargandi (2019) have examined the determinants of energy intensity in EU countries and OPEC countries, respectively, and concluded that energy price, energy tax and per capita GDP can affect

energy intensity. Wurlod and Noailly (2018) analyzed the impact of green technology innovation on energy intensity in 17 OECD countries, and concluded that green technology innovation leads to the reduction of energy intensity in most industries. Canh et al. (2020) used the data of 81 countries and examine the heterogeneous impacts of financial development on the energy intensity among countries with different incomes. Bashir et al. (2021) examined the impact of environmental protection tax on energy consumption and energy intensity in OECD countries.

As far as we know, few scholars have studied the determinants of energy intensity from the local micro level, especially from the city level. Yuxiang and Chen (2010) used China's provincial panel data and concluded that the increase of Chinese government consumption expenditure has significantly improved the energy intensity. In China, the mayor (the chief executive for the city) is the first person responsible for the quality of urban environmental, and also possess the power to formulate environmental policies. Therefore, it is more meaningful to study the impact of policies on energy intensity from the perspective of the cities. Unfortunately, this research is still relatively rare except for the researches of Ma and Yu (2017) and Zhang et al. (2020). Ma and Yu (2017) found that changes in industrial structure (including the increase in the proportion of state-owned enterprises and small-scale enterprises) can reduce urban energy intensity. Zhang et al. (2020a) found that local government environmental regulations can mitigate the financing-energy relationship and reduce energy intensity. Therefore, differ from their researches, we attempt to evaluate the effect of local government policies on energy intensity from the city level.

The "low-carbon zone" policy is a major measure for countries or regions to achieve environmental goal and deal with the global warming crisis. Since 1990, many countries have reached consensus on international agreements of low-carbon development. In 2003, the British government issued the energy white paper "our future energy: creating a low carbon economy" (DTI, 2003). The UN started international climate negotiations in 1990 and signed the Kyoto Protocol in February 2005. In 2007, Japan also put forward the concept of low-carbon society, and pointed out that "without a low-carbon society, there would be no low-carbon economy". Then there are a few scholars who start to quantitatively evaluate the effect of the "low-carbon zone" policy. Difference-in-difference (hereafter called DID) method is a most frequently used method for policy evaluation. For example, Wolff (2014) used the DID method to examine the impact of European low-carbon area policy. Gehrsitz (2017) used the DID method to evaluate the impact of Germany's low-carbon zone policy on air quality and infant mortality. Their researchers concluded that the low-carbon zone policy has significantly improved local air quality and reduced infant mortality. China also has carried out a kind of low-carbon zone policy called low-carbon city pilot policy. In August 2010 and December 2012, China's national development and Reform Commission (NDRC) issued two batches of low-carbon city pilot notices, requiring the pilot cities to combine the adjustment of industrial structure with the optimization of energy structure and energy efficiency, reduce carbon intensity and promote green development. This pilot are considered an inevitable choice for China (Yang and Li, 2013), whose actual effect remains to be verified. This constitutes the research goal of our study.

Our study makes several contributions to exist literature. Firstly, we try to evaluate the impact of "low-carbon city pilot" policy on energy intensity. Previous researchers have found that low-carbon zone policy can effectively improve air quality, but its impact on energy intensity is still to be verified. We use China's low-carbon city pilot policy as a quasi-natural experiment and evaluate its effects on energy intensity. In particular, most of the literature about energy intensity are transnational and focus on developed countries. There are few studies focusing on the regional energy intensity within a country. Therefore, it is innovative to use the samples of Chinese cities and conduct an empirical research on cities' energy intensity. The results show that China's low-carbon city pilot policy has reduced energy intensity remarkably. Secondly, we try to study the heterogeneous impacts of "low-carbon city pilot" policy. As an emerging market country, China's development stage is different from that of developed countries. Low-carbon regional policy may show heterogeneity in China. Especially, China's regional economic development is unbalanced, the per capita GDP of the eastern developed cities has reached the level of developed countries, while the central and western regions are still at the level of developing countries. Cities in different stages of economic development may exhibit different energy intensity. The empirical results show that: low carbon city pilot policy has a more significant inhibitory effect on the energy intensity of Eastern, high economic development and non-heavy industrial cities. Finally, we try to explore the mechanism of "low-carbon city pilot" policy affecting energy intensity. Relevant empirical studies show that green technology innovation and industrial structure optimization can reduce energy intensity. However, whether low-carbon city policy can affect energy intensity through green technology innovation or industrial structure optimization has not been demonstrated. Therefore, we conduct a mediating effect model to test this mechanism. Our results show that the "low-carbon city pilot" policy can reduce the energy intensity by promoting green technology innovation rather than industrial structure optimization.

The rest of our paper is organized as follows: In *Econometrical Tests on the Effect of the "Low-Carbon City Pilot" Policy on Energy Intensity* we conduct the econometric tests on the effect of the "low-carbon city pilot" policy on energy intensity, which mainly includes model design, variables and data and empirical analysis. In *The Heterogeneous Impact of "Low-Carbon City Pilot" Policy on Energy Intensity* is the heterogeneous impact of "low-carbon city pilot" policy on energy intensity. In *Robust Tests* we test the robustness of the previous research conclusions. In *Further Analysis: Impact Mechanism* we further explore the impact mechanism of "low-carbon city pilot" policy on energy intensity. And *Conclusion* concludes the paper.

ECONOMETRICAL TESTS ON THE EFFECT OF THE "LOW-CARBON CITY PILOT" POLICY ON ENERGY INTENSITY

Model Design

Different levels of environmental regulation have heterogeneous effects on regional energy intensity (Hou et al., 2018). When the

level of environmental regulation is low, enterprises tend to reduce pollutant emissions and increase the "end treatment" investment such as sewage and waste gas treatment equipment (Jorgenson and Wilcoxen, 1990; Nur Utomo et al., 2020). At this time, "compliance cost effect" plays a leading role, leading to a positive correlation between environmental regulation and energy intensity. With the continuous optimization and increasing intensity of environmental regulation, enterprises will be forced to pay attention to "prior prevention". For example, they will increase the investment in energy conservation and energy efficiency (Porter and Linde, 1995; Hong et al., 2020). At this time, the "innovation compensation effect" plays a leading role, leading to a negative correlation between environmental regulation and energy intensity. Therefore, the relationship between environmental regulation and energy intensity depends on the size of "compliance cost effect" and "innovation compensation effect".

Some scholars have evaluated the effect of "low-carbon zone" policy. They think that low-carbon technology plays an increasingly significant role in the process of economic development. In practice, developed cities all over the world regard the construction of low-carbon city policy as an important way to improve competitiveness (Hamamoto, 2006). And most of them affirmed its positive role. For example, Cheng et al. (2019) find that "low-carbon city pilot" policy has a positive effect on regional green economic development. According to the notices of China's "low-carbon city pilot" policy, the core of this policy lies in: faced with a growing energy demand, we need to strive to construct an industrial system and consumption mode characterized by low-carbon emissions while developing economy and improving people's livelihood. Therefore, we believe that as an environmental regulation measurement, China's "low-carbon city pilot" policy can force enterprises to save energy and reduce energy intensity, and its "innovation compensation effect" is more prominent than "compliance cost effect". In short, China's "low-carbon city pilot" policy is negatively correlated with energy intensity.

In order to explore the development of economy, realize energy conservation and emission reduction, and promote green development, Chinese government has issued a series of policies and requirements to promote energy conservation and emission reduction. Among them, the most important one is the "low-carbon city pilot" policy. In 2010, NDRC started the first batch of low-carbon city pilot policy, and started the second and third batch of low-carbon pilot policy in 2012 and 2017, respectively. In July 2010, NDRC selected eight cities as the first batch of low-carbon pilot cities. In December 2012, NDRC selected 28 cities (districts and counties) as low-carbon pilot cities. In 2017, the number of low-carbon pilot cities reached a climax, and a total of 45 cities (districts and counties) were selected as low-carbon pilot cities. **Figure 1** plots a map of the two batch of low-carbon pilot cities in China.

From **Figure 1**, we can find that the distribution of these two batch of low-carbon pilot cities is relatively scattered from the west to the east, from the north to the south in China. They not only include the developed coastal cities, but also include the under-developed western cities.

In order to solve the endogeneity problem in literature, we use this pilot policy as a "natural experiment" to construct a DID model. This pilot policy is relatively exogenous and not easily affected by other factors. Therefore, the endogenous problems can be largely avoided. Using the DID research design, we compare the change in energy intensity among low-carbon pilot cities with the change among non-low-carbon pilot cities. The specific model is as follows:

$$EFF_{it} = \beta_0 + \beta_1 Post * Treat + \beta_2 PGDP_{it} + \beta_3 INDUS_{it} \\ + \beta_4 POP_{it} + \beta_5 FDI_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (1)$$

In **Eq. 1**, the subscipt i and t denote the individual and year, respectively. The explained varaible EFF_{it} represent the change in energy intensity, the interaction variable $Post*Treat$ is the key variable. The coefficient β_1 measures the impact of "low carbon city pilot" policy on energy intensity. The variable $Post$ is year dummy variable. When time is in 2009 or 2012, the value is 1, whereas vice versa is 0. The variable $Treat$ is the city dummy variable. When the city belongs to the pilot cities, the value is 1, otherwise it is 0.

In addition, we introduce other control variables according to the relevant theories: 1) the economic development. It is generally believed that countries with higher economic development often exhibit lower energy intensity. This is because the industrial competition in developed countries is more intense, and their R&D department is more higher developed, which makes the energy intensity decrease more (Wu, 2012; Filipović et al., 2015; Li and Liao, 2020). Of course, there are some scholars who believe that the relationship between economic development and energy intensity is uncertain. On the one hand, higher income will increase energy demand and then thus energy intensity; On the other hand, different incomes reflects different development stage, and higher income is often accompanied by the improvement of energy efficiency, which will reduce energy intensity (Jimenez and Mercado, 2014).2) Industrial structure. China's economy has experienced high speed development, followed by the optimization of industrial structure(Li et al., 2020). Luan et al. (2021) found that when the proportion of tertiary industry increase 1%, energy intensity decrease by about 0.03%. Li and Lin (2014) denoted industrial structure by the proportion of secondary industry, and conclude that there is a non-linear (rather than simply promoting or restraining) relationship between industrial structure and energy intensity. 3) Population density. It is generally believed that higher population density will increase the energy demand, and thus the energy intensity (Sadorsky, 2013; Rafiq et al., 2016). 4) Foreign Direct investment (FDI). Scholars believe that the entry of FDI can bring advanced management experience, corporate management system and business philosophy, which will be helpful to the decrease of energy intensity in host countries (Li et al., 2019; Cao et al., 2020; Zhong and Li, 2020). 5) City dummy variable. It is used to eliminate the influence of missing invariable variables such as city characteristic. 6) Time dummy variable. It is used to exclude the impact of macroeconomic events (such as the 2008 financial crisis, etc.).
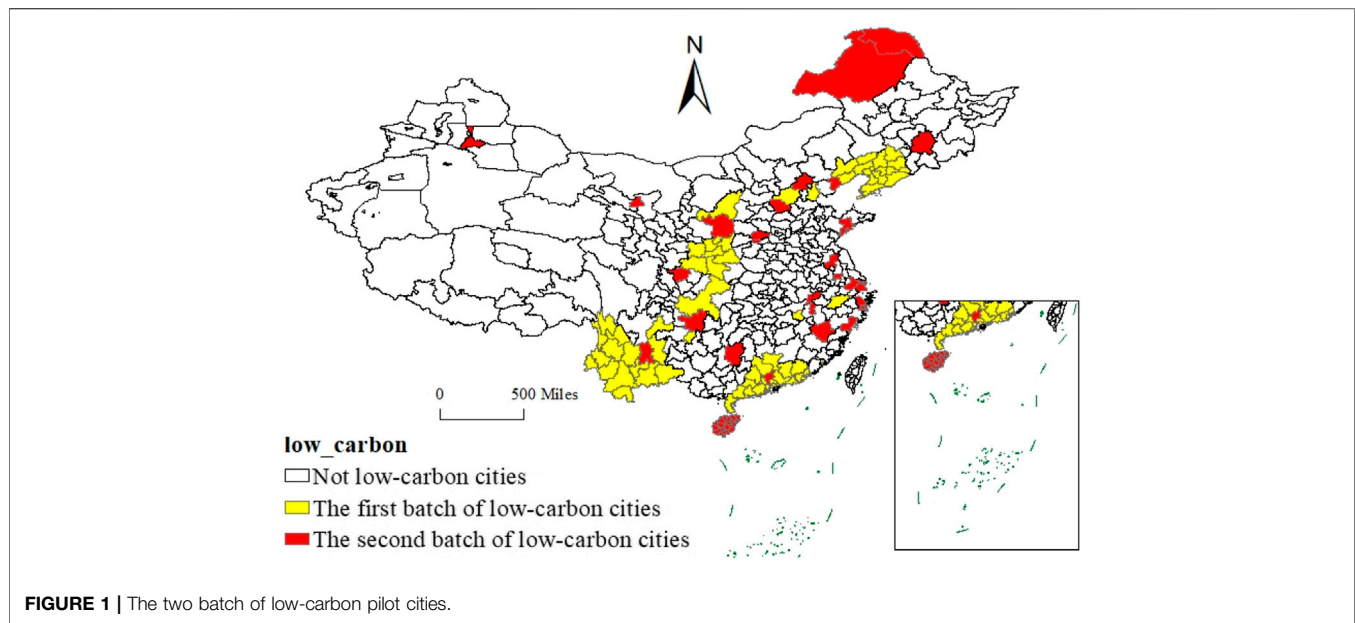
FIGURE 1 | The two batch of low-carbon pilot cities.

TABLE 1 | Variable measurement and data sources.

Variables	Measurement index	Data sources
Energy intensity	Energy consumption per ten thousand yuan gross regional product	Statistical yearbook of provinces and cities
Economic development	per capita GRP	Statistical yearbook of provinces and cities
Industrial structure	The proportion of second and tertiary industries in GRP	China urban statistical yearbook
Population density	The number of permanent residents per unit area	China urban statistical yearbook
FDI	The actually utilized foreign capital which is converted into RMB according to the average exchange rate in the year	China urban statistical yearbook and China statistical yearbook
Technology innovation	The numbers of invention patents	The official website of state intellectual property office
Green technology innovation	The numbers of green invention patents	The official website of state intellectual property office

Notes: We mainly use the definition of WIPO to define the green invention patent, which can be seen in Hong et al.(2021).

Variables, Data and Descriptive Statistics
Variable and Data

Referring to the common method of scholars such as Chang (2014), Lin and Wang (2021) and so on, we measure the energy intensity by energy consumption over GRP. And from the perspective of Chinese cities, the data of the energy use over GRP is more displayed by the change rate, so we use the reduction rate of energy consumption over GRP to indicate the energy intensity. In the control variables, the economic development is expressed in terms of per capita GRP. The industrial structure is denoted by the proportion of second and tertiary industries in GRP, the population density is denoted by the number of permanent residents per unit area, and foreign direct investment is denoted by the actually utilized foreign capital which is converted into RMB according to the average exchange rate in the year.

Table 1 shows the variable measurement and data sources. Due to the data availability and comparability, we mainly collected panel data of 271 cities from 2006 to 2016. The

comparability refers to that since low-carbon pilot policy has been spread to lots of cities, there would be not enough samples as the control group if the samples in 2017 were included." But it may be not clearly expounded. So we add in the paper that "Due to the issue of comparability, we mainly want to examine the impact of the first batch (July 2010) and the second batch (November 26, 2012) of "low-carbon city pilot" with a relatively close time, but not the impact of the third batch (2017). There are two specific reasons: first, in 2017, the lack of data in some regions is more serious after 2018. Second, the third batch of "low-carbon city pilot" are carried out on a large scale. After 2017, most cities have carried out "low-carbon city pilot", so there are not enough reference objects for the comparative analysis of difference-in-difference. The data used in our study are mainly from the statistical yearbook. Specially, the data of energy intensity and economic development are mainly from statistical yearbooks of provinces and cities. The data of industrial structure, population density and actual utilization of foreign capital are from China's urban statistical

TABLE 2 | Descriptive statistical results.

Variable	Obs	Mean	Std. Dev	Min	Max
Id	2,187	132.57	79.86	1	271
Year	2,187	2011.36	2.96	2006	2016
Eff	2,286	−4.56	2.09	−10.34	4.13
lnpgrp	2,178	10.30	0.74	5.40	12.28
Second	2,187	49.31	10.34	14.95	85.64
Tertiary	2,186	37.58	9.31	11.22	80.23
Population	2,187	488.29	344.06	10.02	2,648.11
lnfdi	2,167	11.66	1.77	3.22	16.83

TABLE 3 | Pearson correlation coefficient matrix.

	Eff	lnpgrp	Second	Tertiary	Population	lnfdi
Eff	1					
lnpgrp	−0.053**	1				
Second	−0.087***	0.280***	1			
Tertiary	0.028	0.175***	−0.666***	1		
Population	−0.019	0.109***	0.111***	0.170***	1	
lnfdi	−0.026	0.424***	0.042**	0.412***	0.430***	1

Note: *, **, and *** indicate that they have passed the 10, 5, and 1% significance level tests, respectively.

yearbook, and the average exchange rate of the year is from China's statistical yearbook.

Descriptive Statistics

Before the empirical analysis, we need to conduct descriptive statistical analysis on all variables, and the results are shown in **Table 2**.

It can be seen from **Table 2** that there are 271 sample enterprises in this paper, and the reduction rate of energy intensity is between −10.34 and 4.13%. The proportion of the secondary industry and the tertiary industry in the GRP changes greatly. The proportion of the secondary industry ranges from 14.95 to 85.64, and the proportion of the tertiary industry ranges from 11.22 to 80.23, which indicates that there are great differences in the industrial structure among different cities in China. The minimum value of per capita GRP is 5.4 and the maximum value is 12.28, which indicates that the per capita income of Chinese cities with better economic development has reached the level of high-income countries or regions, while the per capita income of Chinese cities with poor economic development is still at the level of low-income countries or regions, which may lead to the heterogeneous impact of low-carbon city pilot on the energy intensity of these different regions. In addition, we also find that there are great differences between the actual level of foreign investment and population density in different regions.

Before testing the impact of low-carbon city pilot on energy intensity, we need to examine the degree of correlation between various variables to avoid multicollinearity in parameter estimation. Based on this, this paper calculates the correlation coefficient between various variables as shown in **Table 3**. **Table 3** is the Pearson correlation coefficient matrix, which shows the correlation among the variables in the model. Among them, the

TABLE 4 | The results of the impact of low carbon city pilot on energy intensity.

	(1)	(2)	(3)
Post*treat	−0.4177**	−0.4659**	−0.4556**
	(0.182)	(0.183)	(0.194)
lnpgrp		0.2391**	−0.1785*
		(0.110)	(0.107)
Second		−0.0521***	−0.0722***
		(0.017)	(0.025)
Tertiary		−0.0397**	−0.0627**
		(0.018)	(0.031)
Population			−0.0005
			(0.001)
Lnfdi			−0.1495**
			(0.064)
City FE	Included	Included	Included
Year FE	Included	Included	Included
N	2,286	2,281	1963
R^2	0.142	0.149	0.149

Note: Standard errors in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01. In column 1 is the basic model. In column 2 and 3, we further control the variables such as economic development level, industrial structure variables, population density and foreign investment level.

energy intensity has a significant negative correlation with the proportion of the secondary industry and the level of economic development. But in the whole there is no high correlation between the variables. Therefore, we think that there is no serious multicollinearity among the variables, so we can directly conduct the ordinary least squares regression.

Empirical Analysis

Furthermore, we make parameter estimation on the impact of low-carbon city pilot on energy intensity, and the results of parameter estimation are shown in **Table 4**. It can be seen from **Table 4** that the "low-carbon city pilot" policy can reduce the energy intensity. Specifically, in column 1–3 the coefficients of the interaction items are from −0.4177 to −0.4659, and pass the 5% significance level test. It is shown that the pilot policy has inhibitory effect on energy consumption per unit of GRP, which confirms the innovation compensation effect of the pilot policy. In addition, in column 2–3 the coefficients of the regional economic development (lnpgrp) are significantly negative, indicating that with the regional economic development, energy efficiency will be improved and the energy intensity reduced. The coefficients of the variables such as the proportion of the secondary industry and the proportion of the tertiary industry are both significantly in column 2–3. According to the theory of industrial economics, the increase of the proportion of the secondary and tertiary industries reflects the general law of industrial structure evolution, which will bring about the improvement of energy efficiency. This is consistent with our empirical conclusion. The coefficient of FDI are significantly negative, indicating that the higher the foreign investment, the energy intensity is lower. This is due to that the entry of foreign direct investment can bring advanced management experience, enterprise management system and business philosophy, which will improve the energy efficiency in China, and then reduce the energy intensity. The coefficient of

TABLE 5 | The heterogeneous impacts of the pilot policy on the energy intensity in different geographical locations.

	(1)	(2)	(3)
	Eastern regions	Central regions	Western regions
Post*treat	−0.7412***	−0.5293	−0.6576
	(0.255)	(0.401)	(0.518)
lnpgrp	−0.1243	−0.3023	−2.3364***
	(0.129)	(0.212)	(0.831)
Second	0.0278	−0.1249***	0.0036
	(0.048)	(0.027)	(0.032)
Tertiary	0.0565	−0.1155***	−0.0258
	(0.058)	(0.034)	(0.026)
City FE	Included	Included	Included
Year FE	Included	Included	Included
N	1,113	1,168	662
R^2	0.193	0.142	0.240

*Note: Standard errors in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01. In column 1, 2, and 3 the sub-samples are the eastern, central and western regions, respectively.*

the population density fails to pass the statistical test. It may be due to that after controlling variables such as the economic development, the population density will not increase the energy demand and improve the energy intensity.

THE HETEROGENEOUS IMPACT OF "LOW-CARBON CITY PILOT" POLICY ON ENERGY INTENSITY

There are differences in energy intensity among cities with different geographic locations, economic development, and characters such as whether old industrial bases are or not. So we further distinguish cities according to geographic locations, regional economic development, and whether they are old industrial bases or not, and analyze the heterogeneous effects of "low-carbon city pilot" policy on energy intensity.

Cities in Different Geographical Areas

Since the reform and opening up, economic gaps between the eastern regions, the central regions and the western regions in China have always existed and never narrowed. The pace of development in the eastern region continues to accelerate, while the development of central and western regions are restricted by related factors such as backward infrastructure, imperfect market economy system, and backward education development, thus the economic development gap between the East and the west is widening. Generally speaking, the level of China's economic and technological development gradually decreases from east to west, while the abundance of natural resources increases from east to west. Objectively, there are three major economic regions such as the east, middle and west. Therefore, we refer to the research of (Elliott et al., 2013; Zhang et al., 2020) and divide China's cities into eastern, central and western regions according to their geographic location. Among them, the eastern region mainly includes Beijing, Tianjin, Jiangsu, Zhejiang, Fujian, Liaoning, Shandong, Guangdong, Hainan, and Hebei. The central region includes Shanxi, Inner Mongolia, Jilin, Hubei, Hunan, Anhui,

Heilongjiang, Jilin, and Jiangxi. The western region includes Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, and Guangxi. Then we conduct a regression analysis on sub-samples. The results are shown in **Table 5**.

According to **Table 5**, the "low-carbon city pilot" policy have a heterogeneous impact on the energy intensity of different regions, and its impact on the energy intensity of the eastern region is more significant. Specifically, the coefficients of the interaction terms in column 1 are negative and pass the 1% significance test, while the corresponding coefficients in column 2 and 3 are not significant, indicating that after controlling other regional factors, the "low-carbon city pilot" policy can significantly reduce the energy intensity in eastern regions, but has no significant impact on the energy intensity in central and western regions. This may be due to the fact that China's eastern regions have better technical foundation and more talents which are the basis for technology innovation. Specifically, China's eastern regions have superior geographical conditions, agricultural intensification, industrialization and commercialization relative to the central and western regions (Zheng et al., 2020), so they have obvious advantages in attracting talent and foreign investment and technological innovation. Therefore, the low-carbon city pilot policy is easier to promote the eastern regions to increase investment in energy conservation and play an innovative compensation effect to reduce energy intensity.

Cities With Different Economic Development

Furthermore, we divide the samples into regions with high economic development and regions with medium and low economic development level according to the median of the per capita GRP of the region, and conduct sub-sample regression analysis. At the same time, considering the correspondence to different geographical locations in China, we also use the tertiles of per capita GRP and divide the samples into regions with high economic development, medium economic development, and low economic development. Then we conduct a sub-sample regression analysis. The results are shown in **Table 6**.

The analysis in **Table 6** shows that, the "low-carbon city pilot" policy has heterogeneous impacts on the energy intensity of the regions with different economic development, and the impacts of the regions with high economic development and medium economic development are significantly negative, while those of the regions with low economic development are not significant. Specially, from **Table 6**, it is shown that the coefficients of the interaction terms in column 1, 3, and 4 are all negative, and pass the significance test of 5, 10 and 1%, respectively, while those in column 2 and 5 are insignificant. This further confirms previous conclusions that with fiercer industrial competition and higher professional R&D departments, enterprises in economically developed regions are able to respond quickly once policies introduced, which in turn bring down energy intensity even more. Admittedly, this will make the problem worse. Because in fact, compared with energy intensity in the regions with low economic development, those in middle and high economic development regions are generally lower. And the effect of the "low-carbon city pilot" policy is more significant in middle and high economic development regions.

TABLE 6 | The heterogonous impact of "low-carbon city pilot" policy on the energy intensity in regions with different economic development.

	(1)	(2)	(3)	(4)	(5)
	High economic development regions	**Medium and low economic development regions**	**High economic development regions**	**Medium economic development regions**	**Low economic development regions**
Post*treat	−0.7340**	−0.0629	−0.7095*	−1.5941***	−0.1044
	(0.311)	(0.272)	(0.3902)	(0.5339)	(0.3674)
lnpgrp	−1.8881*	−0.4628***	−1.4722	−3.2037**	−0.2953
	(1.019)	(0.173)	(1.2570)	(1.5362)	(0.2008)
Second	−0.0281	−0.0352	−0.0318	−0.0842	−0.0014
	(0.041)	(0.022)	(0.0529)	(0.0718)	(0.0288)
Tertiary	−0.0286	−0.0500*	−0.0179	−0.1215	−0.0027
	(0.027)	(0.028)	(0.0276)	(0.0763)	(0.0352)
City FE	Included	Included	Included	Included	Included
Year FE	Included	Included	Included	Included	Included
N	1,168	1,113	778	774	729
R^2	0.142	0.193	0.127	0.198	0.213

Notes: Standard errors in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01, we classify the samples into sub-samples according to the median values. In column 1-2, we classify samples into two groups. The samples in the two regressions are high regions and medium and low economic development regions respectively. In column 3-5, we classify samples into three groups. The samples in the three regressions are high, medium and low economic development regions, respectively.

The result will worsen with larger differences of energy intensity between the medium-high economic development regions and the low economic development regions.

Cities Belongs to the Old Industrial-Base Areas or Not

Finally, we also analyze the heterogeneous impacts of the policy between the samples according to whether they are old industrial-base areas. Specifically, according to the National Development and Reform Commission's "National Old Industrial Base Adjustment and Transformation Plan (2013-2022)" issued in 2013, we identify 120 old industrial base cities or provincial capital cities. Among them, some of the old industrial-bases are important national energy bases, and usually undertake major technical equipment or the supply of products related to the national economy and people's livelihood. On the whole, the old industrial-bases have the characteristics of high energy consumption and high pollution, and often exhibit higher energy intensity. Therefore, our concern is whether the low-carbon city pilot policy can restrain the energy intensity of the old industrial bases and achieve high-quality development of the old industrial-bases. In order to solve this problem, we divide the sample into old industrial-base areas and non-old industrial-base areas, and perform sub-sample regression analysis. The results are shown in **Table 7**.

The analysis in **Table 7** shows that the "low-carbon city pilot" policy has heterogeneous impacts between old industrial-base area and the non-old industrial-base area, and its impact on the non-old industrial-base is more significant. Specifically, the coefficient of the interaction term in column 1 is insignificant, while the coefficient of the interaction term in column 2 is −0.522 and pass the 5% significance level test. It shows that the "low-carbon city pilot" policy has a significant inhibitory effect on the energy intensity of non-old industrial-bases, but has no significant effect on non-old industrial-bases areas. The reason lies in that their different concerns about environment quality. Specially, most of

TABLE 7 | The heterogeneous impacts of "low-carbon city pilot" policy on energy intensity: old industrial-bases and non-old industrial-bases.

	(1)	(2)
	Old industrial-bases	**Non-old industrial-bases**
Post*treat	−0.7029	−0.5220**
	(0.470)	(0.207)
Lnpgrp	−0.5829*	−0.2250*
	(0.351)	(0.119)
Second	−0.1223***	−0.0424**
	(0.041)	(0.019)
Tertiary	−0.0899*	−0.0411**
	(0.050)	(0.020)
City FE	Included	Included
Year FE	Included	Included
N	662	1,619
R^2	0.240	0.131

Note: Standard errors in parentheses, *p < 0.1, ** p < 0.05, ***p < 0.01. We classify the samples into two sub-samples according to whether the areas are old industrial-bases or not. In column 1-2, we classify samples into two groups. The samples in the two regressions are old industrial-bases and non-old industrial-bases, respectively.

the non-old industrial bases are cities with a relatively developed economy and a higher degree of marketization, and they have more demands for environmental quality, thus more enthusiastic about participating in energy conservation and emission reduction (Li et al., 2019), so with the "low-carbon city pilot" policy introduced, the public in these areas consciously strengthen the supervision of corporate behavior, prompting corporations to improve energy efficiency and reduce energy intensity.

ROBUST TESTS

Parallel Trend Test

The premise of the difference-in-difference method is that the experimental group and the control group are comparable, that is,
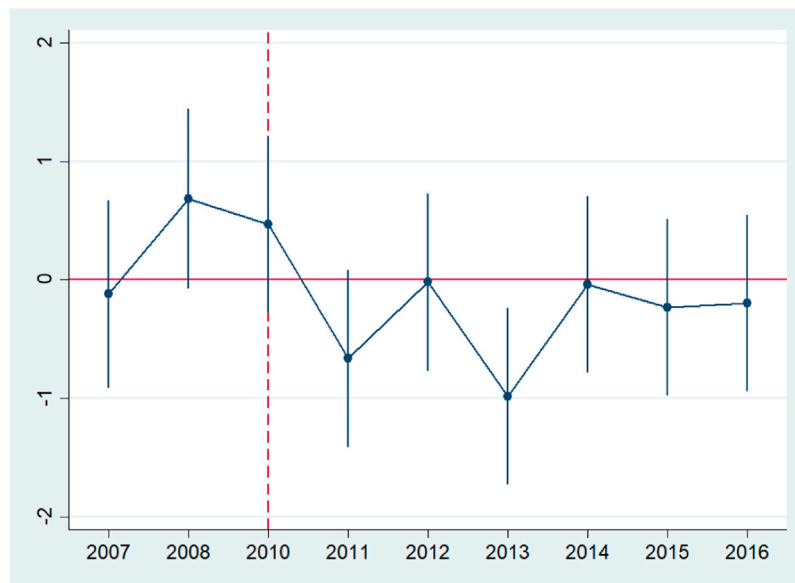
FIGURE 2 | Results of parallel trend test.

if there is no low-carbon city pilot policy, the energy intensity of the treat group and the control group will not change significantly over time and meet the parallel trend assumption. In order to verify this premise, we use the method of (Chen et al., 2018; Hong et al., 2020), use 2009 as the reference year, and add variables before and after the implementation of the policy into the model. The interaction term of the variable is used for event analysis, and the specific model is shown in **Eq. 2**. The coefficients of each interaction term are shown in **Figure 2**.

$$EFF_{it} = \beta_0 + \beta_1 \sum_{t=2007\ t\neq2009}^{2016} Post^t * Treat + \beta_j Controls_{it} + \mu_i + \nu_t + \varepsilon_{it}$$

(2)

It can be seen from **Figure 2** Results of parallel trend test that before the implementation of the low-carbon city policy, there was no significant difference between the control group and the treatment group, but after the implementation of the policy, the energy consumption per GRP of the pilot cities in 2011 and 2013 dropped significantly. Specifically, before the policy implementation, the coefficients of the interaction term are not significant, indicating that the difference in energy intensity between pilot cities and non-pilot cities is not significant before the policy is implemented, that is, the parallel trend assumption is satisfied. It is suitable to use the difference-in-difference method. After the implementation of the policy, the coefficient of the interaction term in 2011 and 2013 significantly dropped to a negative value, and passed the significance test of 10 and 5%, respectively, indicating that with the implementation of the "low-carbon city pilot" policy, the energy intensity was significantly reduced. In other words, the "low-carbon city pilot" policy have a certain inhibitory effect on energy intensity.
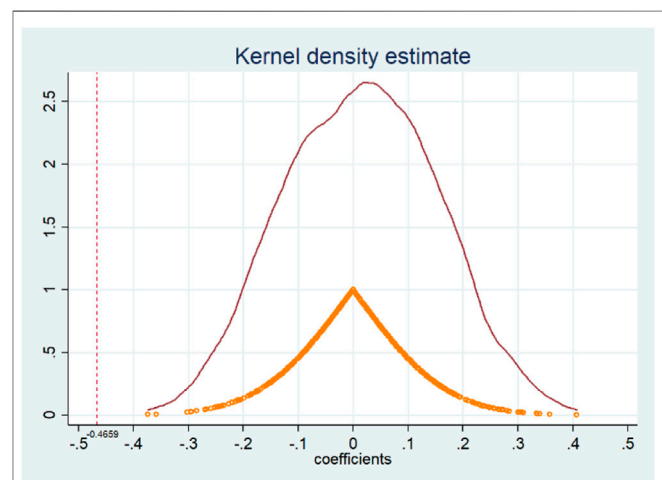

FIGURE 3 | Placebo test results.

Placebo Test

In order to further rule out the differences in energy intensity between pilot cities and non-pilot cities caused by other multiple compound factors, we also conduct a placebo test by constructing a false treatment group and a control group. From the overall sample of 271 cities, 61 cities were randomly selected as the treatment group, and other cities were used as the control group. Through random sampling, a group of false pilot cities and non-pilot cities are constructed. The dummy variable of the pilot city is assigned a value of 1 while the dummy variable of the false non-pilot city is assigned a value of 0, and then make a regression analysis with other control variables added. In this way, random sampling is repeated 500 times. The coefficients of the interaction

TABLE 8 | Robustness test (reset the research period).

	(1)	(2)
	[2007-2016]	[2008-2015]
Post*treat	−0.6615***	−0.8295***
	(0.195)	(0.216)
lnpgrp	−0.1680	−0.1635
	(0.107)	(0.105)
Second	−0.0965***	−0.1526***
	(0.026)	(0.035)
Tertiary	−0.0993**	−0.1677***
	(0.033)	(0.045)
City FE	Included	Included
Year FE	Included	Included
N	1917	1,563
R^2	0.141	0.171

Note: Standard errors in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01. In column 1, the sample period are from 2007 to 2016 (3 years before and after the policy implementation). In column 2, the sample period are from 2007 to 2016 (2 years before and after the policy implementation).

term are used, and we plot the kernel density distribution diagram as shown by **Figure 3**.

It can be seen from **Figure 3** that the estimation result of the benchmark model has passed the placebo test, indicating that the impact of the "low-carbon city pilot" policy on energy intensity has little correlation with other unknown factors, that is, the estimation result of the benchmark model is robust. Specifically, **Figure 3** shows that the estimated coefficients obtained by 500 random processing are distributed near zero, indicating that the unobserved regional characteristics will not affect the estimated results.

Reset the Research Period

Considering that our research period selected are 4 years before and after the implementation of the policy, is somewhat arbitrary. Therefore, in order to enhance the credibility of the conclusions, we further relax this assumption and set the research period as 3 years before and after the policy implementation and 2 years before and after the implementation of the policy for empirical analysis. The results are shown in **Table 8**.

Table 8 shows that when we change the previous research period 2006–2016 to two other period 2007–2016, and 2006–2015, which covers the period 3 years before and after the policy implementation, and the period 2 years before and after the policy implementation, the research conclusions have not substantially changed. This further confirmed the robustness of previous research conclusions. Specifically, the coefficients of the interaction terms in column 1 and column 2 are −0.6615, and −0.8295, respectively, and both pass the 1% significance test. It shows that after changing the research period, the low-carbon city pilot policy still have a significant inhibitory effect on energy intensity.

FURTHER ANALYSIS: IMPACT MECHANISM

The theoretical analysis part of the previous article pointed out that "low-carbon city pilot" policy may contribute to energy conservation and emission reduction by encouraging enterprises to strengthen R&D and innovation, and may also reduce energy intensity by promoting the upgrading of industrial structure. To this end, we further explore the impact mechanism of "low-carbon city pilot" policy based on two perspectives of technological innovation and industrial structure upgrading.

Technological Innovation Mechanism

In order to identify the existence of low-carbon city pilot impact mechanism, we use the mediating effect model to test (Hayes, 2009), the model is set as follows:

$$MEDIATOR_{it} = \alpha_0 + \theta Post * Treat + \alpha_2 PGDP_{it} + \alpha_3 INDUS_{it}$$
$$+ \mu_i + \nu_t + \varepsilon_{it}$$

(3)

$$EFF_{it} = \beta_0 + \lambda Post * Treat + \beta_1 PGDP_{it} + \beta_2 INDUS_{it}$$
$$+ \delta INDUS_{it} + \mu_i + \nu_t + \varepsilon_{it}$$

(4)

In **Eqs. 3**, **4**, $MEDIATOR_{it}$ represents the intermediary variable, and the meaning of other variables is the same as **Eq. 1**. According to the mediating effect model, the first step is to estimate **Eq. 3** and test whether the "low-carbon cities pilot" policy have the promotion effect on technological innovation or industrial structure. If θ is significantly positive, it shows that the "low-carbon cities pilot" policy does have a positive effect on the technological innovation or industrial structure upgrading. The second step is to regress **Eq. 4** to examine the impact of low-carbon city pilot policies and mediating variables on energy intensity. If the coefficients θ, λ, and δ are all significantly, indicating that the mediating effect was significant. However, if in λ and δ at least one of them is not significant, Sobel test is needed.

It can be seen from **Table 9** that low-carbon city pilot policies can reduce energy intensity by promoting regional green technology innovation and technological innovation, which supports the Porter Hypothesis. That is to say, as a favorable environmental regulation, the low-carbon city pilot policy could generate "innovation compensation", eventually leading to the decrease of energy intensity. Specifically, the coefficients of the interaction terms in column 1 and column 3 are both positive, and have passed the 1 and 5% significance tests, respectively, indicating that the low-carbon city pilot policies can significantly promote regional green technological innovation and technological innovation; The coefficients of the interaction terms in column 2 and column 4 are significantly negative, while the coefficients in front of green technological innovation and technological innovation are negative, but they fail the significance test. Therefore, the Sobel test is required, and the test results are significant, indicating that the mediation effect exists.

The Mechanism of Industrial Structure Optimization

"Low-carbon city pilot" policy may affect energy intensity by forming "environmental barriers" to industrial structure

TABLE 9 | The technological innovation mechanisms of low-carbon city pilot policy.

	(1)	(2)	(3)	(4)
	Green technology innovation	**Reduction rate of energy consumption per unit GRP**	**Technology innovation**	**Reduction rate of energy consumption per unit GRP**
Post*treat	1.7826***	−0.4951***	13.1852**	−0.4952**
	(0.184)	(0.187)	(5.345)	(0.202)
Lnpgrp	0.0770	−0.2399**	0.8465	−0.2408***
	(0.112)	(0.110)	(0.518)	(0.083)
Second	−0.0690***	−0.0509***	−0.5495***	−0.0508**
	(0.017)	(0.017)	(0.184)	(0.022)
Tertiary	−0.0253	−0.0382**	−0.1958	−0.0382*
	(0.018)	(0.018)	(0.136)	(0.022)
Gpatent		−0.0230		
		(0.021)		
Patent				−0.0031
				(0.002)
City FE	Included	Included	Included	Included
Year FE	Included	Included	Included	Included
N	2,468	2,250	2,468	2,250
R^2	0.125	0.149	0.160	0.149
Sobel test		−2.331**		−1.969**

Note: Standard errors in parentheses, *p < 0.1, **p < 0.05, ***p < 0.0.01. This table shows estimates of the impact of low-carbon city pilot policy on energy intensity through the intermediary variables. In column 1 and 3, the dependent variables are technological innovation and green technological innovation as the intermediary variables respectively, and the former is indicated by invention patents, while the latter is indicated by green invention patents. The data mainly comes from the website of the State Intellectual Property Office. In column 2 and 4, the dependent variables are both energy intensity variable.

optimization. Environmental regulations require recourses re-allocation in the process of economic development, set up environmental barriers for industrial access, further eliminate backward industries with high energy consumption and high pollution, promote the development of low energy consumption and low pollution industries, and accelerate the "energy saving" upgrade of the economic structure. The entropy index is often used to measure income inequality between regions. We refer to the research of (Zhou et al., 2013; Cheng et al., 2018), and use the entropy index to measure the rationality of the industrial structure. Specifically, the construction of the index is as follows:

$$TL = \sum_{i=1}^{n} \left(\frac{Y_i}{Y}\right) ln \left(\frac{Y_i}{Y} \bigg/ \frac{Y}{L}\right) \quad (5)$$

In **Eq. 5**, Y denotes the GRP, L denotes the number of employees in the whole society. The value of n 1, 2 or 3, representing the primary, secondary, and tertiary industries, respectively. If the industrial structure is in an ideal state and the labor productivity of each industry is equal, the value of TL index value is 0, otherwise, the industrial structure will deviate. Therefore, we use this index as the inverse indicator of industrial structure optimization.

It can be seen from **Table 10** that "low-carbon city pilot" policies cannot reduce energy intensity through the influencing mechanism of the industrial structure. Specifically, the coefficient of the interaction term in column 1 is negative and has passed the 1% significance test, indicating that the "low-carbon city pilot" policy can significantly reduce the deviation of the industrial structure, that is, it can promote the upgrading of the industrial structure in each city. Neither the coefficient of the interaction term or the industry deviation variable in column 2 are

TABLE 10 | The industrial structure optimization mechanism of low-carbon city pilot policy.

	(1)	(2)
	TL	**Eff**
Post*treat	−5.5846***	−0.3665
	(1.024)	(0.232)
Inpgrp	0.4405	0.0508
	(0.607)	(0.133)
TL		−0.0007
		(0.007)
City FE	Included	Included
Year FE	Included	Included
Sobel test	0.101	
N	1,473	1,333
R^2	0.212	0.120

Note: Standard errors in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01, due to the high correlation between the industrial structure deviation index and the proportion of the secondary industry, the proportion of the tertiary industry, so these control variables are not included in the empirical study.

significant. Furthermore, we performed the Sobel test, and the test result is not significant, indicating that the mediating effect does not exist.

CONCLUSION

Energy intensity is related to the sustainable use of fossil energy, and reducing energy intensity is one of the main strategies to deal with practical problems such as climate change and

environmental degradation. The role of national macro-level factors on energy intensity has been basically confirmed, but the role of low-carbon policies at the regional level remains to be investigated. Based on the panel data of 271 cities in China from 2006 to 2016, this paper uses the low-carbon city pilot as a quasi-natural experiment to study the impact of regional-level low-carbon policies on energy intensity, and the following main conclusions are obtained:

First, low-carbon city pilot policies can effectively reduce regional energy intensity. As far as we know, pervious studies have shown that low-carbon city policies can effectively reduce carbon emissions and improve air quality, but whether it can reduce energy intensity remains to be verified. This paper empirically provide evidence for the positive effects of "low-carbon city pilot" policy on energy conservation.

Second, the effects of the "low-carbon city pilot" policy on energy intensity are heterogeneous. This heterogeneity is mainly reflected in different geographical locations, different economic development levels and whether it is a heavy industrial base. Compared with other regions, the low-carbon city pilot policies have a more significant inhibitory effect on the energy intensity of the eastern region, high economic development, and non-heavy industrial regions. This is mainly because, on the one hand, compared with the central and western regions and economically underdeveloped areas, these regions have superior geographical conditions and are easy to attract inflows of people and property. Therefore, low-carbon city pilot policies can more easily promote energy conservation and enhancement in the eastern region. Investment in energy efficiency and other aspects will play an innovative compensation effect to reduce energy intensity. On the other hand, the competition among industries in these areas is more intense, the R&D departments are more professional, and the public's environmental appeals are stronger, which enables related industries to respond quickly after the policy is introduced, which in turn reduces energy intensity.

Finally, "low-carbon city pilot" policy mainly affect regional energy intensity through technological innovation, rather than the mechanism of industrial structure optimization. Through mechanism analysis, we further demonstrated that "low-carbon city pilot" policy will mainly bring innovation compensation effects, promote technological innovation and green technology innovation, and reduce energy intensity. In addition, "low-carbon city pilot" policy have also brought about some problems. For example, "low-carbon city pilot" policy will further increase the energy intensity difference between medium and high economic development areas and low economic development areas.

Based on the research conclusions, we propose the following policy recommendations: First, the government can further promote "low-carbon city pilot" policy nationwide by refining pilot experience, and effectively supervise pilot cities and induce their technological innovation, so as to achieve the goal of energy saving, emission reduction and green development. China's low-carbon city policy is introduced by government departments, and maybe other countries can also introduce this kind of environmental regulation policies to reduce the energy intensity of cities. Second, comparing the results of different types of regions, it can be seen that government should implement differentiated regulations according to local economic conditions, especially for the energy intensity of the central and western regions, low economic development regions, and heavy industrial base regions. Third, the government can formulate policies that encourage technological innovation and green technological innovation, improve the technological innovation, and thus enhance the inhibitory effect of "low-carbon city pilot" policy on energy intensity.

We have evaluated the impacts of "low-carbon city pilot" policy on energy intensity, but due to the availability of data, this article still has some limitations. The optimization and upgrading of the industrial structure is not limited to the evolution of the first, second and third industries, but includes the internal adjustments of various sub-industries. Therefore, the mechanism of industrial structure optimization still needs further research. Moreover, the low-carbon city pilot policy itself is still in the process of gradual advancement, and more in-depth research on this policy can be carried out in future.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, and writing—original draft preparation: MH and SC; Data curation: MH and KZ.

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SUPPLEMENTARY MATERIAL

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