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The Impact of Public Transportation on Carbon Emissions—From the Perspective of Energy Consumption

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Abstract: Background: Transportation has become the second-largest source of global carbon emissions. Promoting low-carbon development by means of public transport and green travel and analyzing the mechanism and path of the carbon emissions reduction effect of public transport have become key to reducing carbon emissions in the transportation field and achieving "carbon peak and carbon neutrality". Methods: The data from 30 provinces (2010–2019) were extracted from China Emission Accounts and Datasets (CEADs), China Energy Statistical Yearbook, China Statistical Yearbook, and China Automobile Statistical Yearbook. The two-way fixed-effect model was used to explore the carbon emissions reduction effect of public transport development level. The mediating-effect model was used to verify the transmission role of energy consumption in the carbon emissions reduction effect of public transport development level. Results: The study suggests that the public transport development level and CO_2 emissions are negatively correlated, showing an "Inverted U-shaped" curve relationship. Energy consumption is the transmission path of the carbon emissions reduction effect of public transport development level. The public transport development level adjusts the energy consumption structure through the traffic substitution effect, energy input optimization effect, and industrial structure optimization effect and then acts on carbon emissions. Moreover, the contribution rate of energy consumption is about 4.22%. In addition, regional heterogeneity is present in the transmission path of the carbon emissions reduction effect of public transport development level based on energy consumption. The carbon emissions reduction effect of public transport development level is more significant in the central and western regions than the eastern and northeast regions of China. Conclusion: The transmission mechanism of energy consumption in the carbon emissions reduction effect of public transport is worthy of attention. To promote low-carbon and circular development in the transportation sector, it is urgent to accelerate the green upgrading of transportation infrastructure, promote the low-carbon transformation of energy production and consumption, promote carbon emissions reduction in public transport, and strengthen the linkage regulation between effective government and an effective market.

Keywords: public transport; carbon emissions; energy consumption

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1. Introduction

In the context of global sustainable development, the environmental pollution caused by carbon emissions has been widely concerning all around the world. According to the statistical data of the International Energy Agency in 2020, transport was the world's second-largest carbon emission source after energy generation and heating. The Beijing Declaration issued by the Second United Nations Global Conference on Sustainable Transportation in 2021 also pointed out that "almost a quarter of the greenhouse gas was emitted by the transport sector". Transport has thus become a key area to promote global low-carbon development and achieve carbon peak and carbon neutrality. Reducing CO2 emissions is also regarded as a main goal for low-carbon development in the transport sector. With the continuous progress of carbon peak and carbon neutrality, it is clearly proposed in the "14th Five-Year Plan 2021" that one of the main goals of economic and social development in China is to "promote the green transformation of production and lifestyle and accelerate the stable and orderly reduction of carbon emissions". Green, low-carbon, and circular development in the transport sector is not only the focus of China's economic reform but also the basis for solving China's resource, environmental, and ecological problems. Against the background of the global spread of COVID-19, the "14th Five-Year Plan" period is not only an opportunity for China to promote the comprehensive green transformation of China's economic society but also a critical period for China's ecological civilization construction to focus on carbon reduction and accelerate pollution and carbon reduction. In 2022, the State Council stressed in the Development Plan for the Modern Comprehensive Transportation System in the 14th Five-Year Period that "by 2025, the development mode in the transport sector will be more sustainable, green production and life modes in the transportation sector will gradually take shape". This means that under the carbon peak goal and carbon neutrality vision, the transport sector is required to implement an intelligent and green development mode and participate in the process of global green transportation reform. China has a large demand for energy in the transport sector, while clean energy has not been fully popularized in the transport sector. New-energy vehicles present a low inventory and permeability. Traditional fuel vehicles still dominate the transport sector, meaning it is faced with the conflict of "high-carbon trend" and "low-carbon orientation" and the dual challenges of "reducing pollutant emissions" and "reducing carbon emissions". In 2022, the National Development and Reform Commission and other departments jointly issued the Implementation Plan for Promoting Green Consumption, stating the importance of "guiding the public to give priority to green transportation ways such as public transport and walking, vigorously develop green transportation consumption, and improve the green and low-carbon level." In the face of the severe ecological and environmental problems and the imperative trend of carbon emission management, priority should be given to the development of public transport. It serves as an important way to support green travel and reduce carbon emissions in the transport sector. In 2020, the number of urban bus and tram vehicles nationwide had reached 704,400, up 1.6% year on year. With the increasing availability of public transport means, the growing trend of green travel, and its beneficial characteristics in energy saving and increasing efficiency, public transit will affect energy consumption to some extent and promote the low-carbon transition in energy consumption. However, the following issues need to be investigated and tested: What is the extent of the carbon emission reduction effect of public transport as one of the green travel modes? Is the energy consumption of economic activities closely related to carbon emission intensity and total amount control? What are the ways in which public transport affects energy consumption and then acts on carbon emission? Therefore, it is necessary to study the environmental protection effect of public transport and explore the mechanism of public transport affecting carbon emissions, so as to adjust the urban public transport layout, improve the green and low-carbon status of transportation infrastructures, promote the construction of low-carbon public transport systems and clean and efficient modern energy systems, drive the transformation and upgrading of energy consumption structures, accelerate the green, low-carbon, and circular development of transport sectors, and power the carbon peak goal and carbon neutrality vision.

2. Literature Review and Research Hypotheses

With the serious damage to the ecological environment caused by increasing CO_2 emissions, a growing number of Chinese and foreign scholars have paid attention to carbon emissions and conducted in-depth research on it. Current research on carbon emission mainly focuses on three aspects. First, different econometric models are used to measure the peak and efficiency of carbon emissions in various industries, such as agriculture [1], logistics [2], and the transportation industry [3]. Second, the impact of various government policies on regional carbon emissions is analyzed based on multi-period differences, such as an ecological civilization construction policy [4], a pilot policy for carbon emission rights trading [5], a pilot policy for low-carbon cities [6], and a pilot policy for innovative cities [7]. The third is to explore the factors influencing carbon emissions. Most of the existing studies focus on analyzing the impact on carbon emissions from the perspectives of industrial structure [8], green technology innovation [9], foreign direct investment [10], energy structure, and economic growth [11].

Transportation mode is also one of the important factors affecting carbon emissions, but there are few studies on it. There are two opposing views in the existing studies on the impact of transport mode on carbon emissions: Based on the traffic substitution effect [12], most scholars hold that the development of public transport can have a substitution effect on non-green travel modes such as private cars, thus producing a carbon emissions reduction effect. In contrast, some scholars believe that the development of public transport will generate new demand for transport flows and further exacerbate environmental pollution based on the traffic creation effect [13]. Between them, the former group's research conclusions have received more extensive support in the academic community. Existing studies have shown that the construction of rail transit [14,15] and subway lines [16] can significantly relieve traffic pressure and traffic congestion, so as to reduce the automobile exhaust emissions caused by traffic congestion; increasing investment in transportation infrastructure can also improve air quality [17]. High-speed rail consumes less fossil fuel in passenger and freight transportation [18]. The opening of high-speed rail will not only effectively reduce carbon emissions but also reduce regional carbon emissions by about 2.4 percent [19].

However, the existing literature on the carbon emission reduction effect of transportation mode only studies the impact on carbon emission from the perspective of the opening of high-speed rail and rail transit, without considering whether the increasing development level of public transport has a carbon reduction effect. Public transport acts as a means of green travel. The increasing development level and availability can not only effectively reduce the ownership rate of private cars of local residents but also reduce the priority given to transportation modes with high-pollution emissions [20]. Electric cars emit 10 to 26 times lower CO_2 emissions than fuel-powered vehicles [21]. In addition, the operation scale of electric vehicles and new-energy vehicles in the public transport sector continues to expand. Jiang Y. et al. [22] concluded that an increase in urban public transport volume and passenger traffic will reduce CO_2 emissions. Based on the environmental Kuznets curve, most scholars found an inverted "U" curve relationship between economic growth and carbon emissions. It is believed that the public transport development level is also the embodiment of the economic development level. A higher level of economic development means higher investment in public transportation construction in the region. Based on the impact of transportation mode on carbon emissions in the existing literature, this paper proposes the first research hypothesis:

Hypothesis 1 (H1) *The increasing public transport development level has a carbon emission reduction effect. An inverted "U" curve relationship is present between the public transport development level and carbon emissions.*

In addition, most literature focuses on the direct impact of public transport on carbon emissions and less on the mechanism. The mechanism and path analysis of the carbon emission reduction effect of public transport is the key to build a green public transport system and reduce the carbon emissions in the transportation field. A few scholars have discussed the impact of the transportation mode on the energy consumption structure in terms of green development. Jin W. et al. [23] considered that increasing investment in transportation infrastructure such as high-speed rail and expressways will help reduce energy consumption and promote the development of low-energy-consumption industries. Public transport such as high-speed rail has developed rapidly due to its low energy consumption, low pollution, and convenience, which can affect the choice of residents' travel modes, substitute for non-green transport modes (such as private cars), and reduce the use of private cars so as to reduce the emissions of automobile exhaust, CO_2, and other pollutants [24]. Private cars are the main source of energy consumption for urban transportation. Public transport is less energy-intensive compared to private cars [19,25]. Zhang X.F. et al. [26] proposed that the construction of urban low-carbon transportation systems has a positive impact on the optimization of urban energy consumption structures. From the perspective of energy demand, residents' demand for public transport will lead to the demand for low-carbon-emission energy, while the demand for private cars will lead to the demand for high-carbon-emission energy. Energy consumption structure is an important factor affecting carbon emissions. Increasing fossil energy consumption will boost carbon emissions, and increasing renewable energy in the energy consumption structure will reduce carbon emissions. The optimization and adjustment of energy consumption structure have a carbon emissions reduction effect [27,28]. Therefore, the effective measures to achieve sustainable development in the transport field are to optimize the energy structure, reduce the energy consumption intensity in transportation, and reduce the carbon emissions [29]. Based on this, this study proposes the second research hypothesis:

Hypothesis 2 (H2) *The public transport development level can promote the optimization and adjustment of the energy consumption structure. The energy consumption structure will play the role of intermediary variable and then act on the carbon emission reduction effect.*

Due to the influence of natural environment, energy, resources, economic development level, policy support, and other factors, the public transport development level and the energy consumption structure are unbalanced in four economic regions. The carbon emission reduction effect of the development level of public transport depends on the perfection of the regional public transport network and the energy consumption structure. In terms of the public transport development level, the public transport infrastructure is relatively backward in western China due to the complex terrain; the developed economy in the eastern region is accompanied by growing investment in the transportation sector and the advanced public transport network. The public transport infrastructure is relatively complete in central and northeast China. Direct or indirect energy consumption and carbon emissions in the production process of the industrial sector result in the proportion of secondary industry being directly proportional to carbon emissions [30]. Eastern China is dominated by tertiary industry, while the central, western and northeast regions are dominated by secondary industry. In particular, the regional economic development in northeast China has always been an extensive development model dominated by industry. Studies have shown that provincial capitals with fewer than 6 million residents and between 12 million to 15 million residents show a carbon emission reduction effect of rail transit [31]; the opening of high-speed rail can significantly reduce carbon emissions in central and western cities, but has no impact on carbon emissions in eastern cities [32]. The traffic creation effect in big cities may also weaken the carbon emission reduction effect of public transport. The increasing public transport development level can reduce regional carbon emissions through energy consumption. Compared with the limited effect on the eastern region dominated by tertiary industry, the marginal effect is more obvious in central, western and northeast China. Therefore, this paper proposes the third research hypothesis:

Hypothesis 3 (H3) *Due to the unbalanced development of public transport and the differences in energy consumption structure in different regions of China, a regional heterogeneity is present in the impact of public transport development level on reducing carbon emissions through energy consumption.*

Public transport is crucial to low-carbon urban development. It is necessary to study the carbon emissions reduction effect of public transport development level and its influence mechanism. Therefore, based on the data from 30 provinces in China throughout 2010 to 2019, this study aims to verify the above three research hypotheses and analyze the carbon emissions reduction effect of public transport development level and its mechanism path. The research framework is shown in Figure 1. Compared to the existing literature, the marginal contribution of this study lies in the following factors: First, in the existing research, the impact of public transport and carbon emissions mostly stays at the theoretical level. This study empirically tests the relationship through the measurement method of two-way fixed-effect model. Second, although the existing studies have investigated the impact of public transport modes such as high-speed rail and subway on carbon emissions, there is insufficient research on the deeper internal causes of the carbon emissions reduction effect of public transport. Attention has been given only to the surface causes such as the increase in high-speed rail and subway lines and the number of urban public transport vehicles. Based on the perspective of energy consumption, this study further explores the transmission path of public transport development level, energy consumption, and carbon emissions so as to deepen the research on the carbon emissions reduction effect of public transport development level. The reduction of traffic carbon emissions should be solved by a combination of economy and environment, that is, controlling traffic pollution and reducing energy consumption [29]. Third, this study measures the development level of public transport in two dimensions: government financial input and consumer behavior choice. The existing research mostly uses the number of urban public transport vehicles or urban public transport passenger volume as the proxy variable of public transport scale, ignoring the joint impact of government financial investment and consumer behavior choice on the development level of public transport.

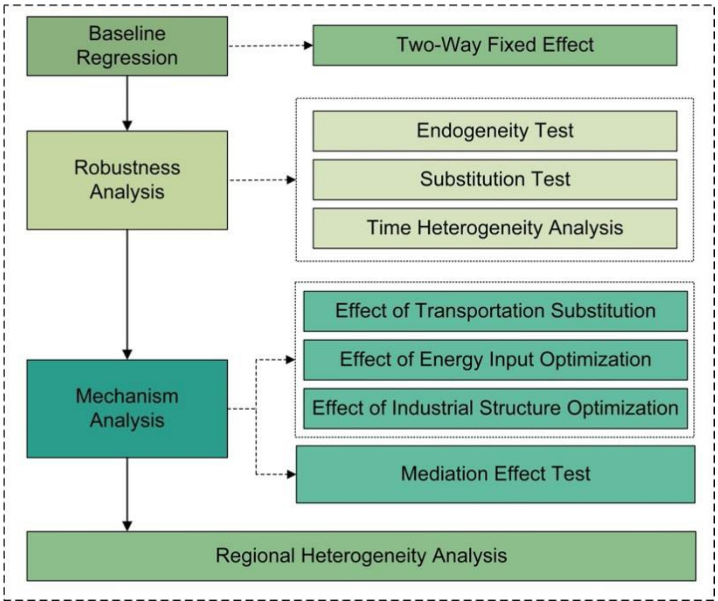

Figure 1. Research framework.

3. Materials and Methods

3.1. Model Specification

To explore the impact of public transport development level on carbon emissions, this study selects a two-way fixed-effect model to perform an empirical test. This is mainly because the data type used in this paper belongs to panel data, which simultaneously involve two dimensions of cross-section and time series. Adopting the original OLS regression will cause the problem of missing variables and heteroscedasticity. The two-way fixed-effect model includes both individual and time fixed effects. Individual fixed effect can control individual characteristics that do not change over time (that is, heterogeneity), and time fixed effect can exclude the influencing factors that change over time [33]. Thus, two-way fixed effect precludes individual characteristics that do not change over time and exogenous shocks that change over time. After adding the control variables that may have influences, the two-way fixed-effect model can further guarantee the accuracy and consistency of the core independent variable coefficients in the panel data types. The two-way fixed-effect model is a rigorous measurement test, and the obtained regression results are more reliable. This is an advantage that ordinary OLS regression and hybrid regression do not have. Specifically, the specific basic regression equation that is constructed in this paper is as follows:

$$lnCO_2 = \alpha lnptdl_{it} + \lambda X_{it} + \upsilon_j + \varphi_t + \varepsilon_{jt} \quad (1)$$

where i and t stand for the i province and the t year; $lnCO_2$ stands for CO_2 emission; lnptdl stands for the public transport development level; α is the core estimation parameter of this paper, indicating the influence coefficient of public transport development level on CO_2 emissions; X represents control variables affecting carbon emissions other than the public transport development level; υ_j and φ_t stand for the individual and time fixed effect; and ε_{jt} is the model error term.

3.2. Model Specification

(1) Explained variable. The explained variable CO_2 (ln CO_2) was measured in the empirical analysis. CO_2 emissions of 30 provinces issued by CEADs throughout 2010–2019 were selected in this paper.

(2) Explanatory variables. Public transport development level (lnptdl) functions as the core explanatory variable in this paper. In the selection of public transport development level index, the public transport passenger volume was added to reflect the public transport load level and consumer behavior choice and measure the public transport development level in two dimensions: government financial input and consumer behavior choice. Specific method: the public transport development level = the number of public buses (electric vehicles) and rail transit vehicles × passenger volume of public buses (electric vehicles) and rail transit. Some scholars have measured the public transport development level using the number of public transport vehicles and the public transport passenger volume [22,26]. Therefore, this paper will test the robustness of the empirical results through using the number of public transport vehicles and the public transport passenger volume as the core explanatory variables.

(3) Control variables. CO_2 emissions are affected by multiple factors. To minimize the statistical bias due to ignoring the missing variables, the influencing factors related to carbon emissions are also considered as control variables. Per capita GDP (lnpgdp): There is a Kuznets "Inverted U-shaped" curve between economic growth and environmental pollution. China is still on the left side of the environmental Kuznets curve [34]. This paper uses per capita GDP as a substitute variable that reflects the level of economic development to control the impact of economic growth on carbon emissions. Population density (lnpd): This is measured by the ratio of the number of permanent residents in each province of China to the land area. Private car ownership (lncar): This is measured by the number of private cars in various provinces of China. The automobile exhaust generated by private cars will increase carbon emissions, and the expected symbol is positive. Foreign direct investment (lnfdi): There are always two opposite views, "pollution heaven" and "pollution halo", about foreign direct investment. The former emphasizes that foreign direct investment will transfer high-intensity polluting industries to the host country; instead, the latter holds that increased foreign direct investment will let advanced technology flow into the host country, increasing energy efficiency and reducing carbon emission intensity [35]. Therefore, in order to control the impact of foreign direct investment on carbon emissions, this paper uses the practice of Wang K.L. et al. [36], who selected foreign direct investment in Chinese provinces and converted it into RMB at the exchange rate of US dollar against RMB in the current year. Industrial added value (lniav): The large amount of primary energy consumed in the industrial sector will increase carbon emissions. Trade openness (lnto): The proportion of total trade to GDP is selected to measure the degree of openness. Trade openness affects energy

intensity through technology spillover, and technology spillover has a great impact on carbon emissions [37].

3.3. Data Description

In this paper, the panel data from 30 Chinese provinces from 2010 to 2019 were selected for the empirical study, and the sample number of each variable was 300. The data on CO2 emissions were obtained from the China Carbon Accounting Database (CEADs) (https://www.ceads.net.cn (accessed on 12 December 2021)). The energy consumption data source was the China Energy Statistics Yearbook (https://data.cnki.net/yearbook/Single/N2021050066 (accessed on 15 December 2021)), and the energy of each classification was converted into 10,000 tons/standard coal according to the energy conversion coefficient in China Energy Statistics Yearbook. The data on other variables were obtained from the China Statistical Yearbook (https://data.cnki.net/yearbook/Single/N2021110004 (accessed on 20 December 2021)) and the China Automobile Industry Yearbook (https://data.cnki.net/yearbook/Single/N2022010158 (accessed on 20 December 2021)). Descriptive statistical results for each variables are shown in Table 1.

Table 1. Descriptive statistics of variables.

Variables	Variable Meaning (Unit)	Sample Number	Mean	Std. Dev.	Min	Max
$lnCO_2$	CO2 emissions (million tons)	300	5.569	0.731	3.365	6.843
lnptdl	Public transport development level	300	21.666	1.554	17.984	25.114
ecs	Energy consumption structure	300	0.807	0.104	0.485	0.991
lnpgdp	GDP per capita (people/yuan)	300	10.763	0.459	9.482	12.009
lnpd	Population density (person/km^2)	300	5.458	1.277	2.053	8.250
lncar	Private cars	300	14.835	0.946	11.876	16.775
lnfdi	Foreign direct investment (ten thousand Yuan)	300	17.587	1.388	14.263	21.022
lniva	Industrial added value (ten thousand yuan)	300	17.923	0.977	15.164	19.792
lnto	Trade openness	300	−1.808	0.967	−4.477	0.383

4. Results

4.1. Baseline Regression Analysis

Through the regression analysis of the benchmark model, the impact of public transport development level on carbon emissions is preliminarily verified. As shown in Table 2, the regression results in columns 1 and 2 suggest that the public transport development level (lnptdl) has a significant inhibiting effect on carbon emission ($lnCO_2$), regardless of the addition of the control variable. After controlling other variables, the inhibitory effect of public transport development level (lnptdl) on carbon emission ($lnCO_2$) increases significantly. Therefore, the result is robust. To test whether there is a nonlinear relationship between the public transport development level and carbon emissions, the quadratic term of public transport development level ($lnptdl^2$) was added for regression, and the results are shown in columns 3 and 4 in Table 2. From the regression results, when other variables are controlled, the quadratic term ($lnptdl^2$) coefficient of public transport development level is significantly negative at the level of 1%, but compared with the primary term coefficient, the quadratic term coefficient of public transport development level is significantly reduced. According to the scatter plot of Figure 2, the quadratic fitting relationship between the public transport development level and CO_2 emissions is roughly in an inverted "U" curve. This indicates that the increasing public transport development level can significantly reduce CO_2 emissions in the short term, but in the long run, the vehicles of public transport will increase, leading to the weakening of the carbon emission reduction effect of the public transport development level.

Table 2. Benchmark regression results.

Variables	$lnCO_2$			
lnptdl	−0.173 *** (−4.40)	−0.187 *** (−5.31)		
lnptdl2			−0.087 *** (−4.40)	−0.093 *** (−5.31)
lnpgdp		−0.332 *** (−3.44)		−0.332 *** (−3.44)
lnpd		2.234 *** (7.20)		2.234 *** (7.20)
lncar		0.388 *** (10.05)		0.388 *** (10.05)
lnfdi		0.025 (1.09)		0.025 (1.09)
lniva		0.107 * (1.88)		0.107 * (1.88)
lnto		−0.060 ** (−2.42)		−0.060 ** (−2.42)
Cons	9.098 *** (10.85)	−7.144 *** (−4.07)	9.098 *** (10.85)	−7.144 *** (−4.07)
R^2	0.400	0.620	0.400	0.620
F statistics	17.320	25.955	17.320	25.955
Sample number	300	300	300	300

Notes: The t-statistic is given in parentheses, and ***, **, and * indicate the significance levels of 1%, 5%, and 10%, respectively.

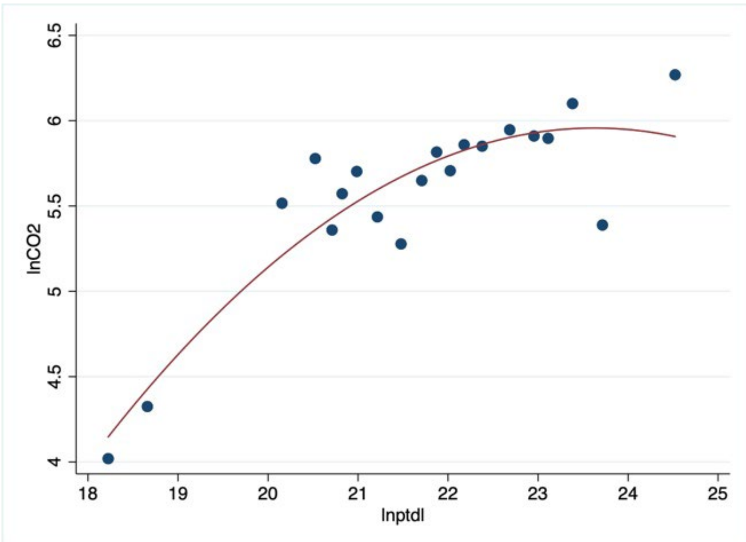

Figure 2. Quadratic fitting relationship between public transport development level and CO_2 emissions.

From the regression results of the control variables, per capita GDP and trade openness have a significant negative impact on carbon emissions, indicating that the exchange of resource consumption for economic growth has been transformed. Population density, private car ownership, and industrial added value have significant positive effects on carbon emissions, which can be attributed to the increasing demand for private cars with the increase in population density. The exhaust gas emission of private cars is also an important factor for carbon dioxide formation. In addition, the development of the industrial sector will consume a great amount of fossil energy, resulting in a continuous increase in total CO_2 emissions.

4.2. Robustness Analysis

4.2.1. Endogeneity Test

In empirical studies examining the impact of public transport development level on carbon emissions, missing variables and bidirectional causality are both important factors causing endogeneity. To avoid endogenous problems, the two-way causality between public transport development level and carbon emissions is discussed here. Areas with a high public transport development level can only reflect their government's financial input and policy support for the public transport infrastructure sector rather than their having low CO_2 emissions. The region's economic growth is likely to be dominated by industrial development. Industrial growth will consume more fossil energy and emit large amounts of carbon dioxide. On the contrary, low CO_2 emissions do not mean a low public transport development level in the region. Therefore, the possible two-way causality between the public transport development level and carbon emissions has a small probability of endogenous problems. Second, missing variables will also make the model estimates inconsistent with the real situation. Although this paper uses the two-way fixed-effect model for benchmark regression and adds a series of control variables related to carbon emissions, it is still difficult to completely eliminate the endogenous problems caused by unobserved influencing factors. To further reduce the impact of endogeneity on the empirical results, the generalized method of moments (GMM) is selected to examine the relationship between the public transport development level and carbon emissions. The GMM can effectively solve the endogeneity problems by adding a lag term as an instrumental variable [38]. Therefore, this paper introduces the lag term of public transport development level (lnptdl) into the model. The regression results are shown in column 1 of Table 3. Sargen test results are not significant, indicating no excessive identification problem of instrumental variables in the GMM. The coefficient of public transport development level is significantly negative, and the estimation results of control variables are also similar to Table 2, which verifies the robustness of the previous conclusions.

Table 3. Robustness analysis regression results.

	GMM	**Two-Way Fixed Effect**		**2010–2013**	**2014–2019**
			lnCO_2		
lnptdl	−0.197 *** (−4.56)			−0.084 (−1.20)	−0.154 *** (−3.57)
lnnpto		−0.233 *** (−3.60)			
lnptpv			−0.222 *** (−4.47)		
lnpgdp	−0.389 *** (−5.01)	−0.359 *** (−3.61)	−0.386 *** (−4.00)	0.516 (1.48)	−0.313 *** (−3.54)
lnpd	2.178 *** (6.77)	2.280 *** (6.98)	1.989 *** (6.40)	1.440 ** (2.08)	1.935 *** (3.90)
lncar	0.240 *** (6.73)	0.404 *** (10.16)	0.380 *** (9.65)	0.517 *** (3.64)	0.180 *** (2.98)
lnfdi	0.017 (0.92)	0.031 (1.32)	0.036 (1.58)	−0.072 (−1.02)	0.031 (1.46)
lniva	0.181 *** (4.14)	0.103 * (1.76)	0.114 ** (1.97)	−0.140 (−0.74)	0.147 *** (3.08)
lnto	−0.021 (−0.85)	−0.068 ** −2.62	−0.082 ** (−3.38)	−0.092 ** (−2.02)	0.001 (0.03)
Cons	−10.660 *** (−4.00)	−9.214 *** (−5.24)	−6.775 *** (−3.72)	−9.638 ** (−2.05)	−4.112 (−1.56)
Sargan	0.002 (0.964)				
R^2	0.996	0.599	0.609	0.690	0.503
F statistics	1028.550	23.688	24.728	17.781	11.650
Sample number	240	300	300	300	300

Notes: The t-statistic is given in parentheses, and ***, **, and * indicate the significance levels of 1%, 5%, and 10%, respectively.

4.2.2. Substitution Test

The core explanatory variables are measured from different angles, which will have an impact on the explained variables. To avoid the bias caused by the selection of measurement indicators, the number of public transport vehicles (lnnpto) and public transport passenger volume (lnptpv) are selected as the proxy variables of the public transport development level. The former (regression results of the number of public transport vehicles) focuses on the perspective of government financial input in public transport infrastructure, while the latter focuses on the impact of consumers' behavior on carbon emissions. Columns 2 and 3 of Table 3 report the regression results of the two-way fixed-effect model, which uses the public transport vehicle number (lnnpto) and public transport passenger volume (lnptpv) as the core explanatory variables. The regression coefficient of the number of public transport vehicles and the public transport passenger volume is significantly negative, which verifies the promotion effect of the public transport development level on reducing carbon emissions, that is, the increasing number of public transport vehicles and public transport passenger volume will have a significant inhibitory effect on CO_2 emissions. The coefficients of other control variables are also similar to Table 2, which further verifies the robustness of the previous conclusions.

4.2.3. Time Heterogeneity Test

The key shift in China's public transport development came in 2013. Although the priority given to the development of urban public transport was mentioned in previous documents, the Ministry of Transport issued the Guidelines on Accelerating the Development of Green, Circular, and Low-Carbon Transport in 2013, which raised the importance of local governments in the development of green and low-carbon transportation systems. Will this shift change the impact of public transport development levels on carbon emissions? To answer this question, the sample data were further divided into two time periods: 2010–2013 and 2014–2019. The regression results are shown in columns 4 and 5 of Table 3. Throughout 2010 to 2013, the regression coefficient of public transport development level was negative and insignificant, which indicates that the public transport development level was not a correlative factor to reducing carbon emissions during this period. Throughout 2014 to 2019, the regression coefficient of public transport development level was significantly negative, indicating that the public transport development level could inhibit carbon emissions. This suggests that under the guidance of national policy, the local governments have enhanced policy support and financial input for low-carbon public transport system construction. Therefore, the increasing public transport development level can effectively curb carbon dioxide emissions. In these two time periods, the regression coefficient of public transport development level changes from -0.084 to -0.154, and the significance level increases gradually, indicating that the carbon emission reduction effect of public transport development level increases gradually. This can also explain why the public transport development level has an overall inhibitory effect on carbon emissions in the full-sample data regression to a certain extent.

4.3. Mechanism Analysis

Increasing carbon emissions have led to serious environmental pollution problems. With the upturn in living standards and the enhanced awareness of environmental protection, residents have put forward higher requirements for ecological and environmental quality, thus forming public opinion pressure and driving the government to carry out environmental governance [39]. The anti-driving mechanism obliges the government to focus on the cleanliness of energy consumption in the processes of life and production, strengthen the development of renewable energy and the investment in renewable energy vehicles, promote the transition of energy investment in public transportation to clean and low-carbon alternatives, and reduce the emissions of carbon pollutants such as carbon dioxide.

Public transport is favored by an increasing amount of residents due to its convenience, low energy consumption, and low pollution, which subtly affects residents' preference for transportation mode. However, green and low-carbon public transport is not only reflected in the impact of low energy consumption on residents' travel modes but also in the substitute of non-green travel modes (private cars). The rising development level and availability of public transport also urge residents to choose public transport. The change in residents' transportation mode and environmental protection understanding has pushed residents with private cars towards public transport, which will reduce the utilization of traditional fossil energy vehicles such as private cars [40]. Private cars are not only the main source of energy consumption but also a major contributor to carbon emissions, while public transport is less energy-intensive compared to private cars [19,25]. Based on the perspective of energy consumption, public transport will lead to low-carbon-emission energy consumption, that is, new energy and high-efficiency fossil energy consumption, while private car travel will lead to high-carbon-emission energy consumption [26]. Therefore, the traffic substitution effect of public transport reduces the carbon emissions in the field of transportation by reducing the demand for high-carbon-emission energy consumption.

In addition, as a mode of transportation, public transport can reduce the transportation cost of enterprises, improve the accessibility between regions, reduce the distance between cities, and accelerate the flow of production and resources between regions [41]. Public transport is dominated by passenger service, which is conducive to the development of service enterprises with strong mobility or dependence on labor factors [42]. Therefore, compared with secondary industry with strong dependence on energy and resources, tertiary industry benefits more easily from public transport. The proportion of tertiary industry in the industrial structure has also increased accordingly. Direct or indirect energy consumption and carbon emissions in the production process of the industrial sector result in the proportion of secondary industry being directly proportional to carbon emissions [30]. The optimization and adjustment of industrial structure has declined the proportion of secondary industry, effectively promoted the optimization of energy consumption structures, reduced the consumption intensity of primary energy, produced energy conservation and emission reduction effect, and reduced CO_2 emissions [43,44].

Accordingly, in theory, the development of public transport is likely to change energy consumption choices and produce a carbon emissions reduction effect through the transportation substitution effect, energy input optimization effect, and industrial structure optimization effect. When considering the effect of the independent variable (X) on the dependent variable (Y), if X has an effect on Y through the variable M, then M will likely play a mediating effect in the relationship between X and Y. At this point, the mediating effect model can be introduced to empirically test whether the mediation role of M exists in the relationship between X and Y [45]. According to the mediating effect test procedure (Figure 3) proposed by Wen Z.L. et al. [45], the specific model setting and inspection steps in this paper are as follows:

$$Y = c_0 + c_1X + controls + \upsilon_j + \varphi_t + \varepsilon_{jt} \tag{2a}$$

$$M = a_0 + a_1X + controls + \upsilon_j + \varphi_t + \varepsilon_{jt} \tag{2b}$$

$$Y = b_0 + c_2X + b_1M + controls + \upsilon_j + \varphi_t + \varepsilon_{jt} \tag{2c}$$

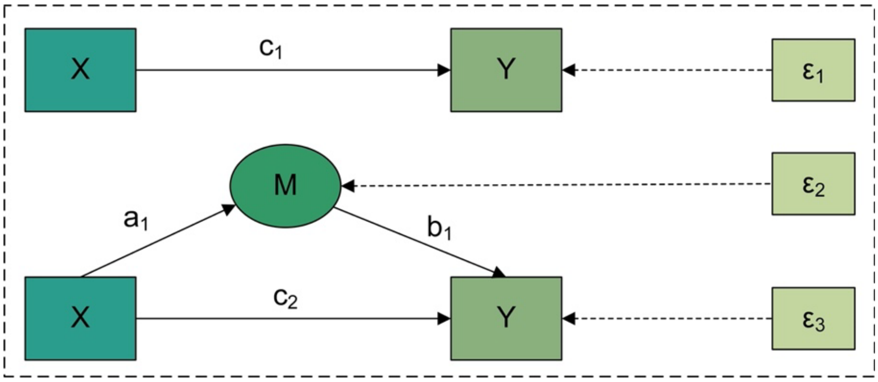

Figure 3. The mediating effect testing procedure.

In the specific model and Figure 3 above, the mediating variable M is energy consumption (ecs). Specifically, this study will follow the following steps of an empirical analysis: first, apply Path A for regression analysis and test the impact of public transport development level on carbon emissions without considering the addition of mediating variables. If the coefficient c_1 is significant, it means that the carbon emissions reduction effect of public transport development level exists, which can be analyzed in the next step; otherwise, the analysis is stopped. Second, apply Path B to investigate the impact of public transport development level on energy consumption and obtain the estimate coefficient a_1. Third, on the basis of Path C, investigate the regression results of Path A after adding the mediating variable M. If the coefficient a_1 of Path B and the coefficient b_1 of Path C are significant, it means that a mediating effect exists, suggesting a mediation role of energy consumption in the causal relationship between public transport and carbon emissions. At this time, observe the coefficient of c_2. If c_2 is not significant, it means that the mediating variable M plays a completely mediating role, which means that the development of public transport affects carbon emissions entirely through the transmission path of energy consumption. If c_2 is significant, it means that M plays a partial mediating effect; that is, in terms of the impact of public transport development on carbon emissions, it produces a carbon emissions reduction effect only partly through the transmission path of energy consumption. Referring to the practice of Zhang and Tang [46], the changes in coefficient c_1 and c_2 reflect the impact of lnptdl on $lnCO_2$ from energy consumption perspectives, with a contribution rate of $(c_1 - c_2)/c_1$. Moreover, two important control variables, population density and private car ownership, and individual and time fixed effect are introduced in the model.

Table 4 shows the test of the transmission mechanism among public transport development level, energy consumption, and carbon dioxide. The public transport development level can reduce CO_2 emissions by promoting the improvement of energy consumption structure. The optimization of energy consumption structure is an important mechanism for the carbon emission reduction effect of public transport development level, with a contribution rate of about 4.22%; so far, Hypothesis 2 is verified. The regression coefficient of the public transport development level is significantly negative, which indicates that the traffic substitution effect, energy input optimization effect, and industrial structure optimization effect produced by the development of public transportation have changed the energy consumption structure. According to the above analysis, with the continuous progress of China's renewable energy development process and the increased development and use of new-energy vehicles in the transportation field, the demand for new energy in public transport has increased. This will help to improve the energy consumption structure, change the public transport model's high energy consumption and high pollution degree, and reduce CO_2 emissions. Advocated by the relevant national circular development policy, the concept of "green and environmental protection" has increasingly affected residents' travel choice. Limited by traffic congestion and other conditions, residents prefer to choose a public transport mode. As can be seen from the estimated results in Table 4, private cars (lncar) have significant positive effects on energy consumption structure and CO_2 emissions, indicating private cars can increase primary energy consumption and aggravate CO_2 emissions. Public transport can substitute for private cars and other transportation modes, thus reducing carbon emissions.

Table 4. Test results of carbon emission reduction effect of public transport development level from the perspective of energy consumption.

Variables	$lnCO_2$	ecs	$lnCO_2$
lnptdl	−0.237 *** (−7.17)	−0.021 ** (−2.02)	−0.227 *** (−6.89)
ecs			0.483 ** (2.43)
lnpd	2.369 *** (8.17)	−0.032 (−0.34)	2.383 *** (8.29)
lncar	0.332 *** (9.33)	0.078 *** (6.85)	0.298 *** (7.75)
Cons	−7.045 *** (−3.98)	0.373 (0.66)	−7.209 *** (−4.10)
R^2	0.596	0.524	0.604
F statistics	31.711	23.678	30.144
Sample number	300	300	300

Notes: The t-statistic is given in parentheses, and ***, **, and indicate the significance levels of 1%, 5%, and 10%, respectively.

4.4. Regional Heterogeneity Analysis

As different regions of China are affected by geographical location, resource endowment, and economic growth, which makes the public transport development level in different regions unbalanced, this study further tests the differences in carbon emission reduction effect in different regions from the perspective of energy consumption. According to the division of China's economic regions, the regression analysis results in the eastern, central, western, and northeast regions are shown in Table 5. The improvement of public transport development level in the central and western regions has a significant emission reduction effect on carbon dioxide. The regression coefficient of public transport development level (lnptdl) in eastern/northeast regions is positive/negative and insignificant. This suggests a regional heterogeneity in the emission reduction effect of public transport development level from the perspective of energy consumption. Hypothesis 3 is validated. Compared with other regions, the provinces in the eastern region have witnessed rapid economic growth, attracted numerous migrants, and increased residents' demand for public transport. To meet the public demand and relieve the traffic pressure and congestion, local governments have added construction and investment in the field of public transport, thus increasing the number of public transport vehicles. The traffic creation effect generated from the expansion of public transport will increase carbon emissions [24], offsetting the substitution effect of public transport on private cars. The public transport development level has not reduced the carbon emissions in the eastern region. Meanwhile, the economic growth in the northeast region has been promoted by high-pollution and high-consumption industry. The direct energy consumption and direct carbon emission generated by industrial development, as well as the indirect energy consumption and indirect carbon emission generated by intermediate inputs in the production process, make the industrial structure optimization effect of the public transport development level and the role of promoting carbon emission reduction unclear. In contrast, the rapid development of public transport in the central and western regions has changed the transportation structure. With the increasing proportion of tertiary industry in the central and western regions, the further optimization of the industrial structure, the traffic substitution effect, and the energy input optimization effect caused by the increasing public transport development level, the public transport development level has significantly reduced carbon emission in the central and western regions.

Table 5. Results of the regional heterogeneity test.

Variables	East	Central of China	West	Northeast
	$lnCO_2$			
lnptdl	0.035 (0.82)	−0.289 ** (−2.52)	−0.275 *** (−5.56)	−0.125 (−0.51)
ecs	−0.037 (−0.20)	7.086 *** (4.88)	0.057 (0.14)	1.815 (0.98)
lnpd	0.333 (1.05)	−0.296 (−0.13)	4.411 (1.03)	9.101 (2.09)
lncar	0.310 *** (5.88)	1.009 *** (4.96)	0.109 *** (6.16)	−1.855 ** (−3.09)
Cons	−1.886 (−0.85)	−6.801 (−0.58)	−10.008 *** (−2.72)	−13.167 (−0.63)
R^2	0.695	0.714	0.770	0.751
F statistics	13.50	7.85	22.13	3.25
Sample number	100	60	110	30

Notes: The t-statistic is given in parentheses, and ***, **, and indicate the significance levels of 1%, 5%, and 10%, respectively.

5. Discussion

The increase in carbon emissions in the transportation sector has led to increasing severity in global climate change and environmental pollution problems. How the public transport development level can produce a carbon emission reduction effect has become a new problem to be solved. This paper selects the panel data of 30 provinces in China from 2010 to 2019, discusses the impact of public transport development level on carbon emissions from the perspective of energy consumption, further supplements the literature on carbon emission reduction effect of public transport development level, and concludes with three valuable findings by establishing a two-way fixed model and an intermediary effect model.

The first finding reveals the carbon emission reduction effect of public transport development level and the inverted "U" curve between public transport development level and carbon emission, which further supplements existing study. This finding may be reasonably explained: public transport acts as a means of green travel, and its increasing availability can not only effectively reduce the ownership rate of private cars of local residents but also reduce the priority given to transportation modes with high-pollution emissions [20]. Moreover, the operation scale of electric vehicles and new-energy vehicles in the public transport sector continues to expand. Electric cars produce 10 to 26 times lower carbon emissions than fuel-powered vehicles [21], and the traffic substitution effect of public transport effectively reduces CO_2 emissions. Based on the environmental Kuznets curve, the existing literature finds an inverted "U" curve relationship between economic growth and carbon emissions. Furthermore, the public transport development level is also the embodiment of the economic development situation in a region. Therefore, there is an inverted "U" curve relationship between the public transport development level and carbon emissions.

The second finding reveals that energy consumption is the transmission path of the carbon emission reduction effect of public transport development level. The public transport development level optimizes and adjusts the energy consumption structure through the energy input effect, traffic substitution effect, and industrial structure optimization effect and then acts on carbon emissions. First, the enhanced awareness of environmental protection and higher requirements for the ecological environment force the government to carry out environmental governance [39]. The anti-driving mechanism obliges the government to focus on the cleanliness of energy consumption in the processes of life and production and promote the transition of energy investment in public transportation to a clean and low-carbon approach. Second, the change in residents' transportation mode and environmental protection understanding has pushed residents with private cars to change to public transport [40]. Public transport is less energy-intensive compared to private cars [19]. Residents' demand for public transport will lead to low-carbon-emission energy consumption, that is, new energy and high-efficiency fossil energy consumption [26]. In addition, public transport is dominated by passenger service, which is conducive to the development of service enterprises with strong mobility or dependence on labor factors [42]. Compared with secondary industry with strong dependence on energy and resources, tertiary industry benefits more easily from public transport. Direct or indirect energy consumption and carbon emissions in the industrial sector result in the proportion of secondary industry being directly proportional to carbon emissions [30]. The optimization and adjustment of industrial structure have declined the proportion of secondary industry, effectively promoted the optimization of energy consumption structure, reduced the consumption intensity of primary energy, and produced energy conservation and emission reduction effects [43,44]. This paper only analyzes the impact of public transport development level on carbon emissions from the perspective of energy consumption. Future research should further explore the impact of public transport development level on carbon emission reduction effect from other perspectives.

The third finding in this research is the regional heterogeneity present in the transmission mechanism of public transport development level based on energy consumption. The carbon emissions reduction effect of public transport development level is more significant in the central and western regions than the eastern and northeast regions. Although the public transport network in the eastern region is relatively developed and tertiary industry accounts for a high proportion, the traffic creation effect generated by the expanding public transport scale in the eastern cities will increase carbon emissions [24] and weaken the carbon emission reduction effect of public transport. In addition, the economic growth in the northeast region has been promoted by high-pollution and high-consumption industry. The direct energy consumption and direct carbon emissions generated by industrial development make the carbon emission reduction effect of public transport development level unclear. In contrast, with the rapid development of public transport, the increasing proportion of tertiary industry, the optimization and adjustment of industrial structure in the central and western regions, the traffic substitution effect, and the energy input optimization effect caused by the public transport development level have produced a significant carbon emission reduction effect. This further suggests that the regional resource and environmental carrying capacity, transportation carrying capacity, and economic development status are important factors in promoting the carbon emission reduction of public transport in the future.

Moreover, this paper also has two research limitations. First, the research scope of the basic data presented in this paper is only derived from China. At present, transport has become the second-largest area of carbon emissions in the world. Reducing traffic carbon emissions has become a common problem faced by countries all over the world. Despite the universal significance and reference value of the results from this study, the underlying data in this paper are currently only from China, limited by the availability of data. In future research, the scope of the data should continue to be expanded for more valuable information. Second, the sample investigation period of this paper is 2010–2019. Theoretically, the research results of this paper have general significance. Even if a longer sample investigation period is selected, the conclusion is still valuable (that is, the development of public transportation will produce carbon emissions reduction effect by changing the choice of residents' energy consumption). However, the carbon dioxide emissions data used in this paper come from the CEADs. The data platform only updated its carbon dioxide emissions data until 2019, making it impossible to observe the carbon emissions reduction effect of the public transport development in 2020 and later years. After the outbreak of COVID-19 in 2020, we predict that due to the influence of COVID-19, the carbon emissions reduction effect may be reduced correspondingly after the use of public transport is restricted. Limited by the availability of data, further analysis and validation cannot be performed in this paper. In the future, after the carbon dioxide emissions data are updated in the CEADs database, the impact of COVID-19 on the internal relationship between public transport and carbon emissions will be the next focus of this research.

6. Conclusions

This paper reveals that the public transport development level has a significant carbon emission reduction effect. Considering endogeneity and missing variables, this study used GMM method, substitution variables, and temporal heterogeneity analysis to retest the relationship, and the results remain robust. The quadratic fitting relationship between the public transport development level and CO_2 emissions shows an "inverted U-shaped" curve. At present, when public transport develops to a certain extent, the reduction effect on carbon emissions will gradually weaken. The public transport development level changes the energy consumption structure through the traffic substitution effect, energy input optimization effect, and industrial structure optimization effect and then acts on carbon emissions. Energy consumption is the transmission mechanism of the emission reduction benefit of the public transport development level. In addition, due to the differences in the development level and industrial structure of public transport in various regions of China, regional heterogeneity is present in the carbon emission reduction effect of the public transport development level from the perspective of energy consumption. The carbon emission reduction effect of public transport development level is more significant in the central and western regions than the eastern and northeaster regions.

7. Implications

The view of this paper is of great significance to understanding the relationship between the public transport development level and carbon emissions and understanding the influence mechanism of the carbon emission reduction effect of the public transport development level. Based on the conclusions of this paper, in order to promote carbon emission reduction in the field of transportation, the first step is to accelerate the green transformation of transportation infrastructure. In addition, deepening the construction of green and low-carbon transportation power; strengthening charging, new energy storage, and infrastructure construction; expanding the production scale of new-energy and clean-energy vehicles; improving the application level of low-carbon public transport infrastructure; and building a travel system dominated by efficient and low-carbon public transport are of importance. Moreover, the second step is to strengthen the linkage regulation between effective government and effective market. The government should give priority to the development of public transport, encourage the public to take green and low-carbon travel, establish and improve the prevention and control mechanism of pollution by transport vehicles, and eliminate high-pollution and high-energy-consumption public transport vehicles. The market should play the role of the price mechanism, gradually improve the ladder price mechanism of energy consumption, and expand the cost gradient of new-energy vehicles and traditional-energy vehicles. It is necessary to build a hierarchical and differentiated price system for public transport to make urban public transport more attractive. Furthermore, the third step is to promote low-carbon transformation in energy production and consumption; accelerate industrial structure upgrading and electrification, new fuel substitution, and other technology innovation; drive the saving of energy and drop in carbon in energy-intensive industry; eliminate backward capacity; control non-renewable energy consumption; speed up new-energy and clean-energy application; strive to adjust the structure of energy production and consumption; and build a clean and efficient modern energy system. In addition, local governments should promote carbon emission reduction of public transport combined with the regional coordinated development strategy, based on the regional resource and environmental carrying capacity, transportation carrying capacity, and transportation operation conditions. The central government should rationally adjust the layout of the public transport network in different regions, supplement the shortcomings of transport infrastructure in the western region, expand the radiation range of urban public transport in the central region, improve the overall efficiency of the public transport network in northeast China, and accelerate the improvement and integration of the operation efficiency of urban public transport in the eastern region.

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