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The impact of resident demand on industrial carbon emissions and the transmission path: Evidence from Zhejiang Province

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A R T I C L E I N F O

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Supply side
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A B S T R A C T

The industrial sector is the main source of carbon emissions in most developing countries. Little research has been conducted on demand-side factors and how the demand side affects industrial emissions through the supply side. Therefore, this article selects 2004–2019 panel data on Zhejiang Province, and a multiple linear regression model and a multiple mediating effects model are adopted to explore the impact mechanism and relationship between demand and industrial emissions. We find the following: (i) There is a significant positive influence of demand on emissions, and (ii) demand has an indirect inhibitory effect on industrial emissions through factor market distortion and an indirect promoting effect through technological innovation and energy consumption. (iii) There are two chain intermediary paths led by factor market distortion that have a negative impact on industrial emissions and a chain path led by technological innovation that has a positive impact.

1. Introduction

According to the Emissions Gap Report 2021 (UNEP) [1], the world is on track for "at least 2.7 °C of warming by the end of the century". Therefore, achieving the Paris Agreement targets will require increasingly stringent emission reduction plans. According to BP's World Energy Statistics Yearbook (2021) [2], global carbon emissions in 2020 amounted to 36.3 billion tons, and China emitted more than 11.9 billion tons. As the largest developing country, China faces enormous demands for economic development and improved living standards. Thus, it will face greater pressure and challenges in the global trend of committing to combatting climate change. As one of the most economically developed provinces along the eastern coast of China, Zhejiang should be among the first provinces to take the lead in achieving the carbon neutrality target.

Zhejiang Province has a well-developed industrial and private economy, ranking fifth among Chinese provinces in terms of the industrial output value in 2021, with an industrial output value as high as 152,000 yuan per capita. In 2021, the total carbon dioxide emissions of Zhejiang's regulated industry amounted to 354 million tons, which was approximately 70 % of the province's total carbon emissions. The Zhejiang industrial sector has a large economic volume and large energy consumption and carbon emissions. Facing enormous challenges, such as the limited space for energy reduction and the increasing difficulty in industrial low-carbon transformation, China has been actively addressing these issues. Therefore, this paper holds great practical significance for China and other developing countries that are still in the process of industrialization.

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For a long time, people generally believed that climate change issues should be addressed from the perspective of production, but the impact of final consumption—the level of residents' demand for products—has been ignored [3–5]. From 2012 to 2021 (except 2020), the contribution of consumption to China's economic growth was more than 50 %, making this factor the top contributor to growth. With the improvement in the consumption level, indirect carbon emissions caused by residents' consumption cannot be ignored: Consumption has become the main driving factor behind the continuous rise in carbon emissions in China [6]. The total retail sales of social consumer goods in Zhejiang Province amounted to 266.298 billion yuan in 2020, and per capita consumption was 41.2 million yuan, which means that in terms of this indicator, Zhejiang ranked third among all provinces. Zhejiang is a small province in terms of energy resources, but it is large in terms of economic impact and energy consumption. This asymmetry between resources and demand means that Zhejiang's carbon neutrality target must be approached from both the supply side and the demand side at the same time. Therefore, it is of great theoretical value and practical significance to take Zhejiang Province as a typical case to study the current situation of industrial carbon emissions and to identify the transmission path of the demand side through the supply side to influence carbon emissions.

2. Literature review

Accomplishing the goal of carbon neutrality holds great significance for the world. Identifying the main driving factors is crucial for achieving this aim. The "carbon" in "carbon neutral" comes from the combustion of fossil fuels; thus, quantifying emissions from the industrial sector is essential for understanding the global carbon budget and implementing appropriate climate policies [7]. Kopidou et al. demonstrated that the supply-side and demand-side effects of industrial products on CO_2 emissions differed significantly between 2000 and 2011 in four Southern European countries and concluded that consumption-based drivers contribute the most to the increase in industrial CO_2 emissions [8]. Therefore, in addition to the extensive discussion of supply-side influencing factors, the impact of demand-side influencing factors needs more attention [9].

A few existing studies have examined demand-side influencing factors, and the available literature mainly covers indicators including resident demand [10,11], renewable energy consumption [12–14], and electricity consumption [15,16]. Among them, the resident demand level is the most representative of the level of overall demand-side development [17]. With the continuous improvement in people's living standards, the demand of residents for high-carbon products, such as electrical appliances and cars, is increasing [18]. However, the views among scholars regarding the relationship between resident demand and carbon emissions are not unanimous. A few scholars believe that to reduce carbon emissions, the relationship between emissions and demand must be severed. In principle, a country can reduce emissions by outsourcing emission-intensive activities while maintaining the same level of demand through imports [19]. However, most scholars still believe that the current development level in China makes it difficult to decouple demand and carbon emissions [20].

The history of carbon emissions in developed countries indicates that the low-carbon transformation of industrial sectors is the key factor driving the carbon increase. The supply-side influencing factors in existing research generally include the industrial structure, technological innovation, market development, etc. The optimization of the industrial structure is not only a decisive factor in achieving carbon emission reduction targets but also an inherent requirement for achieving high-quality economic development in China [21]. Technological innovation is crucial for achieving industrial carbon neutrality because it can improve energy efficiency and promote renewable resources, and its contribution to China's carbon emission reduction is as high as 68.5 % [22]. An effective market trading mechanism can also promote carbon emission reduction in industry and reduce the economic loss caused by green transformation [23], which means that ineffective market development can slow down the progress toward industrial carbon neutrality. In recent years, an increasing number of studies have found that market development factors have a greater impact on achieving carbon neutrality [24,25].

In summary, the literature on industrial carbon emissions has provided useful references, such as demand-side and supply-side impact indicators, but less attention has been paid to the demand-side effects on industrial carbon emissions. According to low-carbon economy theory, future economic development should enhance energy efficiency. The key elements of a low-carbon economy include technological innovation, institutional innovation, and a shift in consumption style. In that case, are the industrial carbon emissions in Zhejiang Province currently affected by residents' demand? What is the transmission path between residents' demand and industrial carbon emissions in Zhejiang Province? How can industrial carbon emissions be effectively reduced from both the supply and consumption sides to promote green development? This paper explores the relationship between residents' demand and industrial carbon emissions and strives to solve these key issues.

The innovative contributions of this paper lie in the fact that it (1) explores the impact of carbon emission reduction in industrial sectors from the perspective of the demand side; (2) analyzes how demand-side factors transmit the effect to the industrial sector through supply-side factors; and (3) proposes countermeasures for reducing carbon in the industrial sector from the perspective of demand-side and supply-side synergy. This paper is organized as follows: Section 3 develops the research hypotheses. Section 4 presents the relevant materials for the empirical analysis, including variable selection, data sources and model settings. Section 5 discusses the research results. Section 6 concludes the study and makes some policy recommendations.

3. Research hypotheses

3.1. The mediating role of industrial structure optimization

In the context of the new mode of consumption, the change in the consumption structure has further improved the incentives of enterprises to engage in research and development (R&D) to follow the change in demand, which in turn has a great impact on the industrial structure. However, the industrial structure is influenced by multiple factors, such as policies and human capital. In the early days, China's industrial structure relied solely on the government's directive plan. Since the reform and opening up, the industrial structure has gradually changed along with economic development, but it still changes mainly with national industrial policy [26]. Consumption growth causes carbon emission growth [27], and adjustment of the industrial structure also directly affects carbon emissions [28]. However, the relationship between consumption and the industrial structure is still controversial. Whether consumption can influence carbon emissions through the industrial structure remains to be confirmed. Thus, we propose the following hypothesis:

Hypothesis 1. The level of resident demand has no indirect effect on industrial carbon emissions through industrial structure optimization.

3.2. The mediating role of factor market distortion

In the production of different goods, the different marginal rates of substitution of factors can lead to deviations between market prices and their opportunity costs and then form a kind of distorted market state [29]. While consumer demand affects consumption, it also stimulates the price of production factors, which in turn affects the cultivation of factor markets. On the other hand, existing economic theories mention that factor market distortion leads to inefficient resource allocation and prompts enterprises to use a large number of tangible factors of production instead of making investments in green technology, resulting in high carbon emissions [30]. Therefore, lower resident demand increases factor market distortion, which further leads to continuous growth in carbon emissions. Therefore, we propose the following hypothesis:

Hypothesis 2. The level of resident demand has an indirect effect on industrial carbon emissions through factor market distortion.

3.3. The mediating role of technological innovation

The consumption of residents influences carbon emissions mainly through the following two technological paths. First, with the upgrading of the consumption structure, the concept of green consumption has gradually become popular, which has greatly promoted the green transformation of enterprises and catalyzed investment in green technology [31]. Second, green development can significantly improve the transformation ability of industrial enterprises' innovation. The relationship between green development and industrial carbon emissions presents an inverted U-shaped curve, and improvements in green development beyond the threshold value of the inflection point can achieve the goal of industrial carbon emission reduction [32,33]. However, it has also been pointed out that an increase in residents' consumption cannot positively impact the growth of green technology. When consumption increases rapidly to a certain extent, industrial enterprises will crowd out the green technology space while increasing R&D, thus causing carbon emissions to rise instead of decline. Therefore, we propose the following hypothesis:

Hypothesis 3. The level of resident demand has an indirect effect on industrial carbon emissions through technological innovation.

3.4. The mediating role of energy consumption

In terms of the relationship between residential consumption, energy consumption and carbon emissions, the focus of carbon emissions is gradually shifting from production to consumption. Household consumption has become an important source of growth in carbon emissions [34]. On the one hand, consumer demand tends to have a positive impact on energy consumption. The theory of demand posits that final energy consumption is actually determined by the overall scale of market demand, including investment, exports and consumption [35]. However, some scholars have advanced the opposite opinion in view of the comparative advantage of household consumption over government consumption, asset investment, net exports and other economic components in terms of energy conservation [36]. On the other hand, energy consumption not only depends on the path of economic development but also reflects the potential for sustainable industrial development, which is closely related to industrial carbon emissions [37]. Therefore, an increase in resident demand affects the level of industrial energy consumption, which in turn directly affects industrial carbon emissions. Accordingly, we propose the following hypothesis:

Hypothesis 4. Resident demand has an indirect effect on industrial carbon emissions through energy consumption.

3.5. The chain mediating path

Based on the relevant literature, it is tentatively proposed that resident demand can also impact industrial carbon emissions through the following chain pathways: (1) The first is the short-chain mediating path. First, factor market distortion prompts enterprises to use a large number of tangible production factors rather than investing in green technological innovation. This weakens the low-carbon development ability of enterprises, thus increasing carbon emissions. Second, the distortion of factor prices has a lock-in effect on the extensive growth model, leading to the undervaluation of factor prices. This makes enterprises continue to use and even increase investment due to the distortion from their incorrect evaluation of outdated equipment that should be eliminated. Third, from the perspective of the transmission path of technological innovation investment, green technology R&D is crucial in the process of green development. With continuous investment in scientific and technological innovation, clean energy substitution and energy efficiency improvement can effectively reduce the level of energy consumption and carbon emissions [38]. (2) The second is the long-chain mediating path. Based on the analysis above, it can be further proposed that the level of resident demand affects the input of technological innovation through factor market distortion, which in turn affects the level of energy consumption and ultimately has a significant impact on industrial carbon emissions. Therefore, based on the analysis above, we propose the following hypotheses, and the specific path is constructed as shown in Fig. 1.

Hypothesis 5. Resident demand affects carbon emissions through the chain path of factor market distortion → technological innovation.

Hypothesis 6. Resident demand affects carbon emissions through the chain path of factor market distortion → energy consumption.

Hypothesis 7. Resident demand affects carbon emissions through the chain path of technological innovation → energy consumption.

Hypothesis 8. Resident demand affects carbon emissions through the chain path of factor market distortion → technological innovation→ energy consumption.

4. Methods

4.1. Variables and data

4.1.1. Explained variable

We calculated China's industrial CO_2 emissions based on the method in Volume II, Energy, of the IPCC National Greenhouse Gas Emissions Inventory 2006 [39]. The formula is as in equation (1).

$$CO_2 = AD_j \times NCV_i \times CC_j \times O_j \tag{1}$$

where CO_2 is CO_2 emissions; AD_j denotes the corresponding fossil fuel consumption; NCV_i denotes the average low-level heat content of different fossil fuels; CC_j is the carbon content of energy source j; and O_j is the oxidation efficiency of energy source j, which denotes the oxidation rate during fossil fuel combustion. Fig. 2 presents objective data that reveal a continuous rising trend of China's industrial CO_2 emissions between 2004 and 2011, followed by stabilization from 2011 to 2019.

4.1.2. Explanatory variable

As the core explanatory variable on the demand side, resident demand is characterized by the per capita consumer spending of residents. Since there are no direct data on residents' consumption from 2013 to 2019 in the Zhejiang Statistical Yearbook, we obtain them by dividing the sum of rural and urban residents' consumption expenditures by the number of permanent residents. We use the 2004 consumer price index as the base period to deflate the data. The data presented in Fig. 3 illustrate a steady annual increase in the consumption levels of residents over time.

4.1.3. Intermediate variables

4.1.3.1. Industrial structure optimization (is). The indicators for measuring the supply-side industrial structure include the proportion of the manufacturing output value to the total industrial output value, the ratio of light and heavy industries and the proportion of the output value of high-energy-consuming industrial sectors. Considering the overall representativeness, the share of the industrial output value in GDP is adopted in this paper [40].

4.1.3.2. Factor market distortion (fac). Based on Zhang et al. (2011), the difference between the degree of factor market development

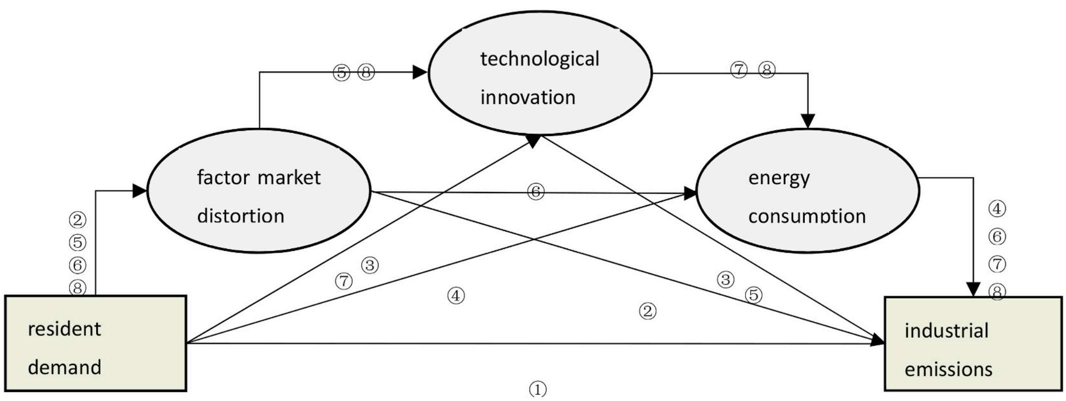

Fig. 1. Hypothesized intermediary effects.

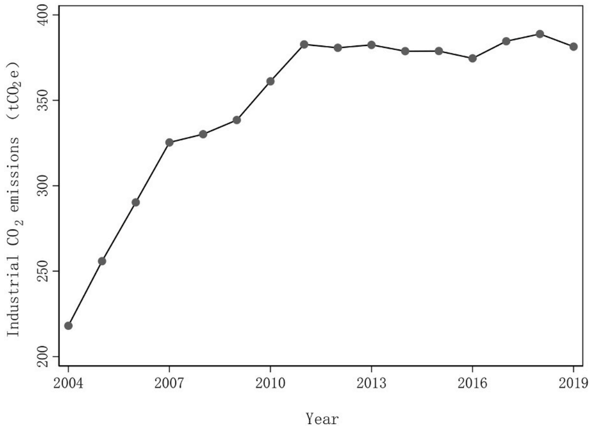

Fig. 2. Industrial CO_2 emissions in China from 2004 to 2019.

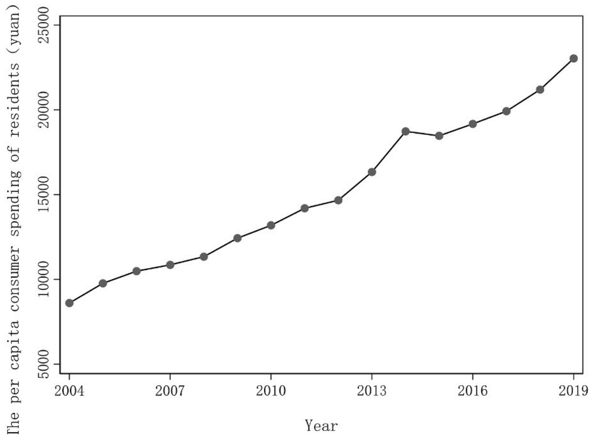

Fig. 3. Per capita consumer spending of residents in China from 2004 to 2019.

in each region and the maximum degree of factor market development in the sample is selected as a proxy variable for factor market distortion [41]. The calculation formula is as in equation (2).

$$fac_{it} = [Max(factor_{it}) - factor_{it}] \,/\, Max(factor_{it}) \times 100 \tag{2}$$

$factor_{it}$ is the factor market development degree index (since the factor market development degree index in the China Sub-Provincial Marketization Index Report is counted up only to 2016, this paper uses the interpolation method for odd years), and the 2017–2019 values are calculated by averaging the growth rate.

4.1.3.3. Technological innovation (te). Technological innovation is measured by the R&D expenditure of industrial enterprises. In addition, the nominal R&D expenditure is deflated by the perpetual inventory method with 2004 as the base period. Its calculation formula is as in equation (3).

$$R_{it} = E_{it} + (1-\tau)R_{i,t-1} \tag{3}$$

where R denotes the capital stock, E denotes the actual R&D expenditure, and τ denotes the depreciation rate. Based on the estimation of the depreciation rate of R&D capital by Griliches and Wu Yanbing [42], this paper takes $\tau = 15$ %. The R&D expenditure price index $= 0.55 \times$ CPI+0.45 $\times$ the fixed asset investment price index, which is used to reduce the nominal R&D expenditure to obtain the actual R&D expenditure in the study period. For the R&D stock in the base period, we assume a geometric decay of R&D expenditures for all periods before the sample and set its average growth rate to g [43]. The base period R&D stock can be expressed as in equation (4).

$$R_1 = E_1 + (1-\tau)E_0 + (1-\tau)^2E_{-1} + \ldots = E_1(1+g)/(g+\tau) \tag{4}$$

4.1.3.4. Energy consumption level (ec). Energy consumption is an important and direct factor affecting industrial carbon emissions. It can represent the degree of energy consumption on the supply side of industry, which also provides effective information for further analysis of the correlation between production capacity and consumption. In this paper, the industrial energy consumption in Zhejiang Province is selected to represent the energy consumption level. To that end, data are obtained from the official website of the Zhejiang Provincial Bureau of Statistics.

4.1.4. Control variables

To eliminate possible bias from missing explanatory variables in the regression estimation results, this paper adds the following control variables in the model: ① the degree of openness, which is expressed as the ratio of regional imports and exports to GDP in each year, and ② the industrial capital stock (ir), that is, the total industrial capital in the current period = the total industrial capital in the previous period - industrial depreciation + the industrial capital increment in the current period. The statistics and variables listed above are summarized in Tables 1 and 2.

4.2. Empirical model

4.2.1. The direct effect of resident demand on carbon emissions

To test the direct effect of resident demand on industrial carbon emissions, the following multiple linear regression model is constructed:

$$lnco_{2it} = \alpha_0 + \beta_1 lncpi_{it} + \sum_{j=1}^{n} \gamma_i CV_{ijt} + \mu_{it} \tag{5}$$

in equation (5), i represents the province, t represents the year, and j is the number of control variables. α_0, β_1 and γ_i are the constant term and the coefficients to be estimated for explanatory variable $lncpi_{it}$ and control variables CV_{ijt}, respectively, and μ_{it} is the random disturbance term.

4.2.2. Mechanism test of the impact of residents' demand level on carbon emissions

To explore the impact path of resident demand on industrial carbon emissions through different intermediary variables, this study adopts a multiple mediating effects model to verify whether there are mediating effects of industrial structure optimization, factor market distortion, technological innovation, and energy consumption on industrial carbon emissions. Furthermore, it explores whether different mediating variables form a chain path affecting industrial carbon emissions. Regarding multiple mediation test methods, the test methods include the Sobel test and bootstrap method. This study uses the bootstrap method to estimate standard errors and establish 95 % confidence intervals (CIs). If 0 is excluded from the CI, the product of the coefficients is statistically significant, and a mediating effect exists [47]. In addition, to generate more accurate estimates, this study takes 500 replicate samples. In this way, the following multiple mediating effects model is constructed:

$$lnco_{2it} = \alpha_0 + a_1 lncpi_{it} + \sum_{j=1}^{n} \gamma_i CV_{ijt} + \varepsilon_{1it} \tag{6}$$

$$ln\, is_{2it} = b_0 + b_1 lncpi_{it} + \sum_{j=1}^{n} \gamma_i CV_{ijt} + \varepsilon_{2it} \tag{7}$$

$$ln\, fac_{2it} = c_0 + c_1 lncpi_{it} + \sum_{j=1}^{n} \gamma_i CV_{ijt} + \varepsilon_{3it} \tag{8}$$

$$ln\, te_{2it} = d_0 + d_1 lncpi_{it} + \sum_{j=1}^{n} \gamma_i CV_{ijt} + \varepsilon_{4it} \tag{9}$$

Table 1
Descriptive statistics.

Variable	Sample Size	Mean	SD	Min	Max
CO_2	16	347.0	51.64	218	388.8
cpi	16	15,147	4483	8605	23,026
is	16	0.596	0.0316	0.540	0.647
fac	16	38.92	18.48	6.084	60.61
te	16	542,359	172,461	413,365	977,898
ec	16	10,100	1494	7237	12,980
to	16	0.585	0.086	0.473	0.725
ir	16	0.499	0.037	0.436	0.543

Table 2
Variable descriptions.

Variable	Definition	Units adopted	Source	Literature	Proxy
CO_2	China's industrial CO_2 emissions	tCO_2e	China Energy Statistical Yearbook	[39]	industrial CO_2 emissions
Resident demand (cpi)	the per capita consumer spending of residents	yuan	dividing the sum of rural and urban residents' consumption expenditures by the number of permanent residents	[5,9]	the core explanatory variable on the demand side
Industrial structure optimization (is)	the share of the industrial output value in GDP	%	the share of the industrial output value in GDP	[40]	the supply-side industrial structure
Factor market distortion (fac)	the factor market development degree index		the China Sub-Provincial Marketization Index Report	[29,41]	factor market distortion
Technological innovation (te)	the R&D expenditure of industrial enterprises	billion yuan	the nominal R&D expenditure is deflated by the perpetual inventory method with 2004 as the base period	[32,42]	technological innovation
Energy consumption level (ec)	the industrial energy consumption in Zhejiang Province	ton of standard coal equivalent	the official website of the Zhejiang Provincial Bureau of Statistics	[25]	the degree of energy consumption on the supply side of industry
Degree of openness (to)	the ratio of regional imports and exports to GDP in each year	%	China's Outward Direct Investment Statistical Bulletin	[44–46]	the degree of openness
Industrial capital stock (ir)	the total industrial capital in the current period	%	the official website of the Zhejiang Provincial Bureau of Statistics	[43]	the industrial capital stock

$$ln\ ec_{2it} = e_0 + e_1 lncpi_{it} + \sum_{j=1}^{n} \gamma_i CV_{ijt} + \varepsilon_{5it} \tag{10}$$

$$lnco_{2it} = f_0 + f_1 lncpi_{it} + g_i x + \sum_{j=1}^{n} \gamma_i CV_{ijt} + \varepsilon_{6it} \tag{11}$$

in equations (6)–(11), a_1 is the estimated coefficients of the core explanatory variables, characterizing the total effect of the level of per capita resident demand on carbon emissions. lnris, lnfac, lnte and lnec are the four mediating variables, i.e., industrial structure optimization, factor market distortion, technological innovation, and energy consumption, respectively. b_1, c_1, d_1, and e1 are the estimated coefficients of the explanatory variables on the mediating variable. γ_i is the estimated coefficients of the control variables CV_{ijt}, and ε_{1it}-ε_{6it} represent random disturbance terms. X in equation (11) represents the four mediating variables, i.e., lnris, lnfac, lnte and lnec, and g_i is their estimated coefficients. The coefficient f_1 is the direct effect of the explanatory variable lncpi on on the explanatory variable $lnco_2$. To eliminate the effects of heteroskedasticity, each variable is logged and centered, denoted as ln.

Then, based on the chain mediating effect test procedure proposed by Preacher and Hayes [48], the chain mediating effects of factor market distortion, technological innovation and energy consumption between resident demand and industrial carbon emissions are tested. Therefore, a chain mediation model is constructed, as equation (12).

$$lnco_{2it} = \beta_0 + \beta_r lncpi_{it} + \beta_1\ ln\, fac_{it} + \beta_2 lnte_{it} + \beta_3 lnec_{it} + \sum_{j=1}^{n} \gamma_i CV_{ijt} + \varepsilon_{7it} \tag{12}$$

Table 3
Estimation results of the nonlinear model and robustness tests.

Variables	$lnCO_2$
Lncpi	0.754***
	(5.16)
lnto	0.693**
	(2.19)
lnir	0.07
	(0.04)
Constant	−1.005
Adj. R-squared	0.745
LM test	P = 0.00

Notes: (a): ***, ** and * denote significance at the 1 %, 5 % and 10 % levels, respectively. (b): Standard errors are presented in parentheses.

5. Results

5.1. Results of the nonlinear model

Before we conduct the mediating effect test, a benchmark regression is conducted on the dependent, independent, and control variables to ensure the accuracy of the subsequent research. To determine whether the four variables ($lnCO_2$, lncpi, lnto, and lnir) are smooth and integrated of the same order, the Hadri Lagrange multiplier (LM) test is used. The result shows that the null hypothesis is rejected and that there is autocorrelation among variables. Therefore, an ordinary least squares (OLS) mixed model should be selected for regression. The regression results show that resident demand and industrial carbon emissions in Zhejiang Province are not only significantly but also positively correlated, and a one unit increase in resident demand increases industrial carbon emissions by 0.754 %, as shown in Table 3. This result indicates that a change in the demand side significantly increases industrial carbon emissions.

5.2. Results of the mediating effect model

5.2.1. Mediating effect test

Table 4 shows the results of the multiple mediation effect test. From the perspective of the transmission path of the industrial structure, resident demand has a negative impact on the industrial structure. This result means that upgrading the industrial structure reduces carbon emissions, but the result is not significant due to the stage of development of the industrial structure. The industrial sector has effectively promoted social and economic development, but this is not directly related to consumption. Philippson also pointed out that the impact of the industrial structure on carbon emission efficiency is not significant, and the impact of consumption on carbon emissions through the industrial structure remains to be discussed [49]. Therefore, industrial structure optimization does not have a significant mediating effect on the relationship between resident demand and industrial carbon emissions, and hypothesis 1 holds.

In terms of the transmission path of factor market distortion, an increase in resident demand eases the distortion of factor market development, and a 1% point increase in resident demand can make the negative development of the factor market decrease by 0.479 %. Factor market distortion further promotes the increase in carbon emissions, and a 1% point increase in factor market distortion increases carbon emissions by 1.373 %. As in Lu, Hengfan et al. [50], factor market distortion may lead to a decrease in the efficiency of energy use. In terms of the indirect effect, the coefficient is −0.393, and the 95 % CI does not contain 0, which indicates that resident demand reduces carbon emissions by increasing factor market distortion, and Hypothesis 2 holds. In terms of the direct effect, the coefficient is 0.860, and the product of the direct effect and the indirect effect is negative, while the total effect coefficient is positive at 0.467. These results indicate that there is a "masking effect" of factor market distortion on carbon emissions, which makes the total effect coefficient decrease by 0.397. This further indicates that an improvement in the demand level can activate the market and optimize the allocation of various resources in the market to promote market development and further reduce carbon emissions.

Table 4
Results of the bootstrap test for mediating effects.

Variables	path	effect	coefficient	std	95 % confidence interval	
					min	max
industrial structure optimization	$Lnis—Lncpi$	–	−2.334***	0.269	−0.148	0.044
	$Lnco_2—Lnis$	–	2.080**	0.489	−1.372	0.742
	$Lnco_2—Lnis—Lncpi$	Indirect	−0.487	0.148	−0.5209	0.038
	$Lnco_2—Lnis—Lncpi$	Direct	0.954***	0.086	0.264	0.637
	$Lnco_2—Lncpi$	Total	0.467***	0.081	0.294	0.640
Variables	path	effect	coefficient	std	95 % confidence interval	
					min	max
factor market distortion	$Lnfac—Lncpi$	–	−1.942***	0.288	−2.5598	−1.3233
	$Lnco_2—Lnfac$	–	0.203***	0.054	0.086	0.318
	$Lnco_2—Lnfac—Lncpi$	Indirect	−0.393***	0.094	−0.573	−0.203
	$Lnco_2—Lnfac—Lncpi$	Direct	0.860***	0.119	0.603	1.112
	$Lnco_2—Lncpi$	Total	0.467***	0.081	0.294	0.640
Variables	path	effect	coefficient	std	95 % confidence interval	
					min	max
technological innovation	$Lnte—Lncpi$	–	−0.776***	0.125	−1.044	−0.509
	$Lnco_2—Lnte$	–	−0.587***	0.076	−0.750	−0.424
	$Lnco_2—Lnte—Lncpi$	Indirect	0.456***	0.160	0.151	0.816
	$Lnco_2—Lnte—Lncpi$	Direct	0.011***	0.069	−0.137	0.160
	$Lnco_2—Lncpi$	Total	0.467***	0.081	0.294	0.640
Variables	path	effect	coefficient	std	95 % confidence interval	
					min	max
energy consumption level	$Lnec—Lncpi$	–	0.479***	0.044	0.3831	0.575
	$Lnco_2—Lnec$	–	1.373***	0.325	0.671	2.075
	$Lnco_2—Lnec—Lncpi$	Indirect	0.658***	0.221	0.125	1.011
	$Lnco_2—Lnec—Lncpi$	Direct	−0.192	0.165	−0.545	0.165
	$Lnco_2—Lncpi$	Total	0.467***	0.081	0.294	0.640

In terms of the transmission path of technological innovation, resident demand has a negative effect on technological innovation: When consumption increases by one percent, the supply side attaches 0.766 % less importance to green technology, and the decrease in technological innovation further causes an increase in carbon emissions. This finding is consistent with the research of Saliba et al., who stated, "In the long run, a decrease in ecological degradation was caused by an increase in technological innovation in China" [51]. The regression coefficient of the indirect effect is 0.456, and the result is significant, which indicates that technological innovation has a positive intermediary effect. Therefore, hypothesis 3 is valid. The regression coefficient of the direct effect is 0.011, and it is also statistically significant. In terms of the overall effect, the regression coefficient is 0.467, which is the same as the product of the direct and indirect effects. These results indicate that there is no masking effect. The improvement in the level of demand reduces the development of technological innovation, which may lead to insufficient development of green technology and make it difficult to offset the current situation of carbon emissions caused by production increasing year by year.

Looking at the traditional path of the energy consumption level, energy consumption increases by 0.479 % for every 1% point increase in resident demand. In turn, a 1% point increase in energy consumption causes a 1.373 % increase in carbon emissions. The product of the two regression coefficients is positive, and the indirect effect is positive with a coefficient of 0.658; thus, hypothesis 4 holds. The direct effect coefficient is −0.191 and nonsignificant, and it reduces the degree of the positive effect in the total effect. These results mean that the mediating effect from energy consumption is a full mediation and that energy consumption on the supply side has a strong positive mediating effect on carbon emissions. Therefore, it can be concluded that the effect of resident demand on industrial carbon emissions is mainly mediated by energy consumption.

In summary, the test results of the mediating effects show that except for industrial structure upgrading, the proposed mediating variables have significant mediating effects. Resident demand suppresses industrial carbon emissions by alleviating the distortion of the supply-side factor market and promoting the input of scientific and technological innovation. It can also eliminate industrial carbon emissions by reducing energy consumption. However, the mediating effect path of industrial structure optimization is not statistically significant.

5.2.2. Multiple chain mediating effects

The findings above show that factor market distortion, technological innovation and energy consumption play significant mediating roles in the impact of resident demand on industrial carbon emissions. To explore whether there is a multimediated chain transmission effect, this paper further continues to explore the chain mediating effect by using significant variables as chain mediating variables. The results are shown in Table 5.

Regarding the transmission path of resident demand level → factor market distortion → technological innovation → carbon emission, the 95 % CI does not contain the number 0, which shows the existence of this intermediary effect path. The indirect effect coefficient is −0.321; thus, overall, this chain mediating effect pulls down the total mediating effect by 50.313 %. This result indicates that resident demand can further negatively affect the supply-side market by influencing green technological innovation, which in turn affects industrial carbon emissions. It also indicates that consumption can optimize factor markets and thus improve the level of technological innovation and ultimately achieve lower industrial carbon emissions. Therefore, hypothesis 5 holds.

For the transmission path of resident demand level → factor market distortion → energy consumption level → carbon emissions, the indirect effect coefficient is 0.211, but the 95 % CI contains 0, which means that the effect is not significant. These results indicate that consumption growth does not directly affect the level of energy consumption through supply-side market development. Therefore, hypothesis 6 does not hold.

Regarding the transmission path of resident demand level → technological innovation → energy consumption level → carbon emissions, the indirect effect coefficient of 0.545 is statistically significant. This result shows that consumption directly affects supply-side technological development, which in turn affects the energy structure and ultimately has a positive impact on carbon emissions. This result is in contrast to the result that consumption first affects the supply-side market and then affects investment in technological innovation. This also confirms that R&D investment has a certain inhibitory, often lagging, effect on carbon emissions; thus, the role of R&D investment is an infiltration process. Therefore, hypothesis 7 holds.

In terms of the transmission path of resident demand level→ factor market distortion → technological innovation → energy consumption level → carbon emissions, the indirect effect coefficient is −0.266 and statistically significant. Overall, this chain mediating effect pulls down the total mediating effect by 41.693 %. Based on the correlated short chain above, we confirm that factor market

Table 5
Results of multiple chain mediating effects.

Variables		$Lnco_2$
Overall mediating effect		0.638**
		[0.114 , 1.0915]
Chain mediating effect	$Lncpi \rightarrow Lnfac \rightarrow Lnte \rightarrow Lnco_2$	−0.321**
		[-0.531 , -0.038]
	$Lncpi \rightarrow Lnfac \rightarrow Lnec \rightarrow Lnco_2$	0.211
		[-0.076 , 0.543]
	$Lncpi \rightarrow Lnte \rightarrow Lnec \rightarrow Lnco_2$	0.545**
		[0.084 , 1.307]
	$Lncpi \rightarrow Lnfac \rightarrow te \rightarrow Lnec \rightarrow Lnco_2$	−0.266**
		[-0.624 , -0.049]

distortion is negatively associated with technological innovation, while technological innovation is positively associated with energy consumption, which also confirms that factor market distortion → technological innovation → energy consumption level in this chain has a negative influence overall. The Porter effect suggests that optimizing factor markets can effectively stimulate enterprises to conduct technological innovation, which in turn affects energy consumption and has a negative impact on carbon emissions. With reference to the infiltration process, since the transformation of technology takes time, although the chain indirect effect is weakly negative, the total effect is still positive. That is, there is a masking effect [52]. This also indicates that consumption has a weak positive impact on carbon emissions. Therefore, hypothesis 8 holds.

In summary, there are three chain paths through which the resident demand level affects industrial carbon emissions: (1) the transmission path of resident demand level → factor market distortion → technological innovation → industrial carbon emissions, which presents a negative effect; (2) the transmission path of resident demand level → factor market distortion → technological innovation → energy consumption level → carbon emissions, which also has a negative impact; and (3) the transmission path of resident demand level → technological innovation → energy consumption level → carbon emissions, which has a positive effect. Based on the overall mediating effect, resident demand has a significant positive overall mediating effect on industrial carbon emissions through the three mediating variables, and the total mediating effect is 0.638 and is significant at the 5 % level.

6. Conclusions and implications

This article innovatively explores the relationship and transmission mechanism between residential consumption and industrial carbon emissions. Taking Zhejiang Province as an example, we tested the transmission path and impact of the demand side on industrial carbon emissions by using a multiple mediating effects model. Studying a case with small energy resources such as Zhejiang Province, which is also a strong industrial province, has important reference value for provinces or countries with strong energy resource constraints. The main findings are as follows: (i) The results of the benchmark regression show that there is a significant positive effect of resident demand on industrial carbon emissions, which means that resident demand exacerbates industrial carbon emissions. Each one unit increase in resident demand increases industrial carbon emissions by 0.756 %. (ii) The results of the multiple mediating effects test show that resident demand has an indirect inhibitory effect on industrial carbon emissions through the intermediary path of factor market distortion and an indirect promoting effect through the two intermediary paths of technological innovation and energy consumption. (iii) The results of the chain mediating effect test show that there are two chain intermediary paths, including factor market distortion → technological innovation and factor market distortion → technology innovation → energy consumption level, which negatively affect industrial carbon emissions. The positive impact on industrial carbon emissions is transmitted through the chain intermediary path of factor market distortion → technological innovation and factor market distortion → technological innovation → energy consumption. Based on the findings above, the following implications can be drawn:

(1) The impact of demand-side factors on industrial carbon emissions should be emphasized, and the green low-carbon concept should be developed to promote the transformation and upgrading of consumption patterns. On the one hand, improvements in resident demand will reduce green technology and increase energy consumption, thus increasing industrial carbon emissions, which indicates that promoting the concept of green consumption is important for reducing industrial carbon emissions. This is also similar to some research findings showing that the expansion of trade and consumption has stimulated economic development, and these economic factors have also led to environmental problems, such as an increase in carbon dioxide pollution [53–55]. On the other hand, consumption can reduce carbon emissions by mitigating market distortion, which shows that a good consumption structure can promote the optimal allocation of production factors. Therefore, the orderly development of consumer demand under the regulation of macro policies should be encouraged. The government should fully mobilize the flexibility of the market, improve various types of protection systems, and strengthen the supply-side reform of the market. Doing so will help shape a good market atmosphere and further correct the degree of factor market distortion to effectively reduce industrial carbon emissions.

(2) The intermediary effect of supply-side factors should be strengthened, and structural reform in the industrial sector should be promoted. We should pay more attention to the negative impact of factor market distortion and formulate market development policies based on actively promoting the balance of supply and demand to improve enterprises' incentives to engage in technological innovation. The "crowding-in" effect of government subsidies on industrial R&D investment should continue to be amplified, and the proportion of renewable energy R&D should increase. Research has confirmed the significance of technological advancement and energy efficiency in mitigating carbon emissions [56]. Therefore, industrial enterprises should actively follow the national carbon neutrality policy and adjust the direction of investment and technology research, for example, in solar energy technology and carbon capture, utilization, and storage (CCUS) technology. To make full use of the mediating effect of supply-side factors, we should not only attach importance to the positive effect but also reduce the transmission of negative factors.

(3) Cooperation with the dual-factor effect of the demand side and supply side should be promoted to accelerate green and low-carbon development in industrial sectors. Achieving the goal of carbon neutrality is a long-term and systematic task. We must promote effective synergy between demand-side management and supply-side structural reform. From the demand side, the government must encourage residents to change their original consumption structure and simultaneously transform the consumption structure and consumption concept to promote supply transformation through demand reform. From the supply side, industrial enterprises must address their high energy consumption, high pollution and high emissions. Research has indicated that enhancing energy efficiency can effectively reduce carbon emissions [57]. It is very important to increase

investment in green technological innovation and continuously improve energy efficiency to effectively reduce industrial carbon emissions and promote the realization of carbon neutrality.

There are some limitations to this study that require attention in future research. The data in this study were up to date only to 2019 and not to 2023 due to data availability. Meanwhile, This study proposes hypotheses based on the literature and explores the transmission paths between demand and industrial carbon emissions. However, there are still other possible transmission paths that were not discussed in this paper. In addition, the relationship between various intermediate variables was not presented due to the lack of significance in the empirical results. Future research should explore this issue in greater depth. Comparative research is required to explore the heterogeneity of other provinces, although Zhejiang Province exemplifies the specificity and typicality of China.

Data availability

Data will be made available on request.

CRediT authorship contribution statement

Huiqin Jiang: Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Funding acquisition, Conceptualization. **Yingying Zhang:** Validation, Investigation. **Yixuan Li:** Writing – original draft, Software, Data curation. **Zhaohang Yu:** Validation, Supervision. **Chen Feng:** Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] United Nations Environment Programme, The heat is on: a world of climate promises not yet delivered ,emissions gap report[EB/OL], 2021 (2021-10-27). [2021-10-26], https://www.unep.org/zh-hans/resources/emissions-gap-report-2021.
[2] The Catalyst review Newsletter group.bp's statistical review of world energy 2021, The Catalyst Review Newsletter 7 (2021) 34.
[3] Q. Ding, S.I. Khattak, M. Ahmad, Towards sustainable production and consumption: assessing the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions (CO_2) in G-7 nations, Sustain. Prod. Consum. 27 (2021) 254–268, https://doi.org/10.1016/j.spc.2020.11.004.
[4] A.A. Abraham, S.A. Tomiwa, A. Mehmet, et al., The dynamic impact of biomass and natural resources on ecological footprint in BRICS economies: a quantile regression evidence, Energy Rep. 8 (2022) 1979–1994, https://doi.org/10.1016/j.egyr.2022.01.022.
[5] J.L. Fan, H. Liao, Q.M. Liang, et al., Residential carbon emission evolutions in urban–rural divided China: an end-use and behavior analysis, Appl. Energy 101 (1) (2013) 323–332, https://doi.org/10.1016/j.apenergy.2012.01.020.
[6] Y. Wang, M. Shi, CO_2 emission Induced by urban household consumption in China, Chinese Journal of Population Resources and Environment 7 (3) (2009) 59–63, https://doi.org/10.1109/ICIFE.2010.5609316.
[7] L. Zhu, National carbon emissions from the industry process: production of glass, soda ash, ammonia, calcium carbide and alumina, Appl. Energy 166 (11) (2015) 239–244, https://doi.org/10.1016/j.apenergy.2015.11.005.
[8] W. Chao, Z. Jin, L. Zhihui, et al., Structural decomposition analysis of carbon emissions from residential consumption in the Beijing-Tianjin-Hebei region, China, J. Clean. Prod. 208 (C) (2019) 1357–1364, https://doi.org/10.1016/j.jclepro.2018.09.257.
[9] D. Kopidou, D. Diakoulaki, Decomposing industrial CO_2 emissions of Southern European countries into production- and consumption-based driving factors, J. Clean. Prod. 167 (5) (2017) 1325–1334, https://doi.org/10.1016/j.jclepro.2017.05.183.
[10] Q. Huang, H. Zheng, J. Li, et al., Heterogeneity of consumption-based carbon emissions and driving forces in Indian states, Advances in Applied Energy 4 (11) (2021), 100039, https://doi.org/10.1016/j.adapen.2021.100039.
[11] K. Dervis, S.A. Tomiwa, Do public-private partnerships in energy and renewable energy consumption matter for consumption-based carbon dioxide emissions in India? Environ. Sci. Pollut. Control Ser. 28 (23) (2021) 1–14, https://doi.org/10.1007/s11356-021-12692-5.
[12] S.A. Tomiwa, N.U. Edmund, A. Zahoor, et al., Determinants of consumption-based carbon emissions in Chile: an application of non-linear ARDL, Environ. Sci. Pollut. Control Ser. 28 (32) (2021) 1–15, https://doi.org/10.1007/s11356-021-13830-9.
[13] H.A. Fakher, R. Inglesi-Lotz, Revisiting environmental Kuznets curve: an investigation of renewable and non-renewable energy consumption role, Environ. Sci. Pollut. Control Ser. 29 (58) (2022) 87583–87601, https://doi.org/10.1007/s11356-022-21776-9.
[14] S.A. Athari, The impact of financial development and technological innovations on renewable energy consumption: Do the roles of economic openness and financial stability matter in BRICS economies? Geological Journal (2023) https://doi.org/10.1002/gj.4863.
[15] Q. Jiang, S.I. Khattak, Z.U. Rahman, Measuring the simultaneous effects of electricity consumption and production on carbon dioxide emissions (CO_2e) in China: new evidence from an EKC-based assessment, Energy 229 (8) (2021), 120616, https://doi.org/10.1016/j.energy.2021.120616.
[16] R.D. Özbay, S.A. Athari, C. Saliba, et al., Towards environmental sustainability in China: role of Globalization and Hydroelectricity consumption, Sustainability 14 (7) (2022) 4182, https://doi.org/10.3390/su14074182.
[17] Q. Cao, W. Kang, S. Xu, et al., Estimation and decomposition analysis of carbon emissions from the entire production cycle for Chinese household consumption, J. Environ. Manag. 247 (2019) 525–537, https://doi.org/10.1016/j.jenvman.2019.06.044.
[18] W. Liu, The indirect carbon emission from household consumption in China between 1995-2009 and 2010-2030:A decomposition and prediction analysis, Comput. Ind. Eng. 128 (2019) 264–276, https://doi.org/10.1016/j.cie.2018.12.031.
[19] T.I.Patrick A.N. Elisabeth, A carbon footprint proportional to expenditure -A case for Norway? Ecol. Econ. 131 (2017) 152–165, https://doi.org/10.2139/ssrn.2425600.

[20] R. Atikur, H. Afzal, C. Songsheng, The impact of foreign direct investment, tourism, electricity consumption, and economic development on CO_2 emissions in Bangladesh, Environ. Sci. Pollut. Control Ser. 29 (25) (2022) 37344–37358, https://doi.org/10.1007/s11356-021-18061-6.
[21] Y. Chai, X. Lin, D. Wang, Industrial structure transformation and Layout optimization of Beijing-Tianjin-Hebei region under carbon emission Constraints, Sustainability 13 (2) (2021) 643–663, https://doi.org/10.3390/su13020643.
[22] H. Duan, S. Zhou, K. Jiang, et al., Assessing China's efforts to pursue the 1.5°Cwarming limit, Science 372 (6540) (2021) 378–385, https://doi.org/10.1126/science.aba8767.
[23] H. Sun, G. Gao, Research on the carbon emission regulation and optimal state of market structure: based on the perspective of evolutionary game of different stages, Oper. Res. 56 (4) (2022) 2351–2366, https://doi.org/10.1051/ro/2022088.
[24] J. Zhang, K. Wang, W. Zhao, et al., Corporate social Responsibility and carbon emission intensity: is there a Marketization threshold effect? Emerging Markets Finance and Trade 12 (2020) 1–13, https://doi.org/10.1080/1540496x.2020.1854219.
[25] Y. Li, L. Yan, K. Wei, et al., Study on the influence of household consumption on energy consumption under the threshold of rising House price, IOP Conf. Ser. Earth Environ. Sci. 546 (2) (2020), 022002, https://doi.org/10.1088/1755-1315/546/2/022002.
[26] S. Dai, W. Zhang, Y. Wang, et al., Examining the impact of regional development policy on industrial structure upgrading: Quasi-Experimental evidence from China, Int. J. Environ. Res. Publ. Health 19 (9) (2022), https://doi.org/10.3390/ijerph19095042, 5042-5042.
[27] Y. Yan, A. Pan, C. Wu, et al., Factors influencing indirect carbon emission of residential consumption in China: a case of Liaoning province, Sustainability 11 (16) (2019) 4414, https://doi.org/10.3390/su11164414.
[28] Y. Sun, Y. Liu, Z. Yang, et al., Study on the decoupling and Interaction effect between industrial structure upgrading and carbon emissions under dual carbon targets, Int. J. Environ. Res. Publ. Health 20 (3) (2023) 1945, https://doi.org/10.3390/ijerph20031945.
[29] S. Qiao, T. Shen, R. Zhang, et al., The impact of various factor market distortions and innovation efficiencies on profit sustainable growth: from the view of China's renewable energy industry, Energy Strategy Rev. 38 (2021), 100746, https://doi.org/10.1016/j.esr.2021.100746.
[30] J. Han, J. Miao, G. Du, et al., Can Market-Oriented Reform Inhibit Carbon Dioxide Emissions in China? A New Perspective from Factor Market Distortion, vol. 27, 2021, pp. 1498–1513, https://doi.org/10.1016/j.spc.2021.03.020.
[31] S.I. Khattak, M. Ahmad, Z.U. Haq, et al., On the goals of sustainable production and the conditions of environmental sustainability: does cyclical innovation in green and sustainable technologies determine carbon dioxide emissions in G-7 economies, Sustain. Prod. Consum. 29 (1) (2022) 406–420, https://doi.org/10.1016/j.spc.2021.10.022.
[32] P. Gao, Y. Wang, Y. Zou, et al., Green technology innovation and carbon emissions nexus in China: does industrial structure upgrading matter? Front. Psychol. 13 (2022) https://doi.org/10.3389/fpsyg.2022.951172, 951172-951172.
[33] L. Rongrong, H. Xinyu, W. Qiang, Do technical differences lead to a widening gap in China's regional carbon emissions efficiency? Evidence from a combination of LMDI and PDA approach, Renew. Sustain. Energy Rev. 182 (8) (2023), 113361, https://doi.org/10.1016/j.rser.2023.113361.
[34] J. Zhang, Z. Zheng, L. Zhang, et al., Digital consumption innovation, socio- economic factors and low-carbon consumption: empirical analysis based on China, Technol. Soc. 67 (2021), https://doi.org/10.1016/j.techsoc.2021.101730.
[35] L. Wang, L. Huang, Effect of Chinese industrial structure upgrading on household consumption structure: evidence from CHIP data, J. Phys. Conf. 1941 (1) (2021), 012015, https://doi.org/10.1088/1742-6596/1941/1/012015.
[36] Y. Li, Y. Li, T. Chen, el al, Research on the Impact of upgrading of consumption structure on energy intensity under the background of urban and rural dual economy, IOP Conf. Ser. Mater. Sci. Eng. 793 (1) (2020) 395–401, https://doi.org/10.1088/1757-899x/793/1/012058.
[37] D. Cang, C. Chen, Q. Chen, et al., Does new energy consumption conducive to controlling fossil energy consumption and carbon emissions?-Evidence from China, Resour. Pol. 74 (2021), 102427, https://doi.org/10.1016/j.resourpol.2021.102427.
[38] Gi Yang, D. Zha, X. Wang, et al., Exploring the nonlinear association between environmental regulation and carbon intensity in China: the mediating effect of green technology, Ecol. Indicat. 114 (C) (2020), 106309, https://doi.org/10.1016/j.ecolind.2020.106309.
[39] B.T. Aaron, P.M.K. David, T. Jenn-Yun, Tests of the three-path mediated effect, Organ. Res. Methods 11 (2) (2008) 241–269, https://doi.org/10.1177/1094428107300344.
[40] M.F. Bellemare, T. Masaki, T.B. Pepinsky, Lagged explanatory variables and the estimation of causal effect, J. Polit. 79 (3) (2017) 949–963, https://doi.org/10.1086/690946.
[41] J.P. Kristopher, F.H. Andrew, Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models, Behav. Res. Methods 40 (3) (2008) 879–891, https://doi.org/10.3758/brm.40.3.879.
[42] Y.M. Wei, L. Wang, H. Liao, el al, Responsibility accounting in carbon allocation: a global perspective, Appl. Energy 130 (2014) 122–133, https://doi.org/10.1016/j.apenergy.2014.05.025.
[43] W. Wang, B. Yu, X. Yao, et al., Can technological learning significantly reduce industrial air pollutants intensity in China?-Based on a multi-factor environmental learning curve, J. Clean. Prod. 185 (2018) 137–147, https://doi.org/10.1016/j.jclepro.2018.03.028.
[44] A. Mujtaba, P.K. Jena, D. Mukhopadhyay, Determinants of CO2 emissions in upper middle-income group countries: an empirical investigation, Environ. Sci. Pollut. Control Ser. 27 (10) (2020), https://doi.org/10.1007/s11356-020-09803-z.
[45] W. Qiang, Z. Fuyu, L. Rongrong, Free trade and carbon emissions revisited: the asymmetric impacts of trade diversification and trade openness, Sustain. Dev. (2023), https://doi.org/10.1002/sd.2703.
[46] W. Qiang, W. Lili, L. Rongrong, Trade openness helps move towards carbon neutrality—Insight from 114 countries, Sustain. Dev. (2023), https://doi.org/10.1002/sd.2720.
[47] Z. Griliches, Issues in assessing the contribution of research and development to productivity growth, Bell J. Econ. 10 (1) (1979) 92–116, https://doi.org/10.2307/3003321.
[48] H.H. Bronwyn, M. Jacques, Exploring the relationship between R&D and productivity in French manufacturing firms, J. Econom. 65 (1) (1995) 263–293, https://doi.org/10.1016/0304-4076(94)01604-x.
[49] Aaron Philippsen, Energy input,carbon intensity and cost for ethanol produced from farmed seaweed, Renew. Sustain. Energy Rev. 38 (2) (2014) 609–623, https://doi.org/10.1016/j.rser.2014.06.010.
[50] H. Lu, J. Peng, X. Lu, Do factor market distortions and carbon dioxide emissions Distort energy industry chain technical efficiency? A heterogeneous Stochastic Frontier analysis, Energies 15 (17) (2022) 6154, https://doi.org/10.3390/en15176154.
[51] C.B. Saliba, F.R. Hassanein, S.A. Athari, et al., The dynamic impact of renewable energy and economic growth on CO2 emissions in China: Do Remittances and technological innovations matter? Sustainability 14 (21) (2022), 14629 https://doi.org/10.3390/su142114629.
[52] M.E. Porter, C. Van der Linde, Toward a new conception of the en-vironment- competitiveness relationship, J. Econ. Perspect. 9 (4) (1995) 97–118, https://doi.org/10.1257/jep.9.4.97.
[53] W. Qiang, S. Jiayi, L. Rongrong, et al., Linking trade openness to load capacity factor: the threshold effects of natural resource rent and corruption control, Gondwana Res. (2023), https://doi.org/10.1016/j.gr.2023.05.016.
[54] W. Qiang, S. Jiayi, K.P. Ugur, et al., Digital economy and carbon dioxide emissions: Examining the role of threshold variables, Geosci. Front. (2023), https://doi.org/10.1016/j.gsf.2023.101644.
[55] Q. Wang, X. Wang, R. Li, Does Urbanization Redefine the Environmental Kuznets Curve? an Empirical Analysis of 134 Countries, vol. 76, 2023, 103382, https://doi.org/10.1016/j.scs.2021.103382, 1.
[56] L. Rongrong, H. Xinyu, W. Qiang, Do technical differences lead to a widening gap in China's regional carbon emissions efficiency? Evidence from a combination of LMDI and PDA approach, Renew. Sustain. Energy Rev. 182 (8) (2023), 113361, https://doi.org/10.1016/j.rser.2023.113361.
[57] L. Rongrong, L. Lejia, W. Qiang, The impact of energy efficiency on carbon emissions: evidence from the transportation sector in Chinese 30 provinces, J] Sustainable Cities and Society 82 (7) (2022), 103880, https://doi.org/10.1016/j.scs.2022.103880.