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Digital Inclusive Finance and Urban Carbon Emission Intensity: The Mediating Roles of Industrial Structure Upgrading and Household Consumption Level

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Abstract

Against the backdrop of the increasingly urgent global climate governance situation, carbon emission reduction has gone beyond the simple scope of environmental protection and become an import benchmark for measuring the quality and sustainability of economic and social development. Drawing on data from 233 prefecture-level cities in China over the period 2015–2024, this study investigates the impact of digital inclusive finance (DIF) on urban carbon emission intensity (CI). The findings indicate that DIF significantly mitigates the effect on CI. Heterogeneity analysis further indicates that this mitigating effect is more pronounced in cities with higher initial CI. DIF also exerts a stronger influence on curbing CI in environmental protection cities and non-central cities. The results also confirm that industrial structure upgrading (ISU) and household consumption level (HCL) serve as mediating mechanisms in the causal pathways. Based on the above conclusions, this paper puts forward suggestions concerning the popularization and expanded coverage of DIF. The coordinated implementation of these suggestions helps DIF fully exert its bridging role between financial and environmental sustainability, providing robust instrumental support for achieving regional carbon emission reduction targets and comprehensively advancing the sustainable development of cities.

Keywords: digital inclusive finance; carbon emission intensity; industrial structure upgrading; household consumption level

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Academic Editor: Sajid Anwar

Received: 21 May 2026

Revised: 20 June 2026

Accepted: 26 June 2026

Published: 1 July 2026

1. Introduction

A thorough examination of the global Sustainable Development Goals (SDGs) reveals that carbon emissions have never been an isolated environmental issue, but a complex problem intertwined with multiple dimensions including economic structure, technological progress and financial systems. For this reason, the 2030 Agenda for Sustainable Development does not address climate change as a standalone objective; instead, it delivers progress in tandem with targets such as SDG 7, SDG 9, SDG 11 and SDG 12, fully embodying the systematic thinking underpinning sustainable development.

Following the implementation of emerging digital technologies, the development of financial services has received powerful impetus. They optimize business processes and operational efficiency within financial institutions, driving the continuous evolution of financial services towards greater intelligence and openness [1]. The academic community has already produced a wealth of research on carbon emissions. In research on traditional finance and carbon emission intensity (CI), scholars hold differing views based on their perspectives. Existing studies suggest that traditional finance conducts deposit, loan, settlement, and securities transactions through offline physical outlets, serves customer groups with sound credit records and sufficient assets, and has exerted certain positive effects on curbing CI. Chen Liang explored the relationship between digital financial and carbon emissions within China's provinces. The findings indicate that green finance converts environmental benefits and climate risks into benchmarks for pricing and decision-making through traditional financial instruments such as credit and bonds, channeling capital into green industries. As a branch of financial development, it directly advances the growth of a low-carbon economy. In turn, the increasingly improved ecological environment brought about by the low-carbon economy further fuels the green transformation of the financial sector itself [2]. Some scholars take a contrary view. Haseeb's study of data from the BRICS countries found that whilst financial development drives economic growth, it also fuels a persistent rise in carbon emissions [3]. Other scholars have also pointed out that financial development broadens enterprises' access to finance and facilitates industrial clustering, thereby increasing energy consumption and driving up carbon emissions [4,5]. The final school of thought holds that in early stages of financial development, credit growth fueled the expansion of energy intensive industries, leading to a rapid rise in carbon emissions. As green financial instruments become more widespread and technological innovations take effect, capital is being channeled towards clean energy and helps to mitigate carbon emissions [6,7]. The interplay between these two opposing forces has produced a dynamic pattern in which carbon emissions first rise and then decline.

Digital inclusive finance (DIF) is characterized by its inclusiveness and convenience. It merges digital technologies to effectively lower the barriers to accessing financial services and reduce transaction costs, whilst keeping operational costs under control. It focuses on providing convenient financial products and services to low-income groups, rural residents, and small and medium-sized enterprises (SMEs) which are often difficult for traditional financial institutions to reach [8,9]. DIF solves the problems of low efficiency and information asymmetry existing in traditional financial services [10]. At present, most scholars are examining how DIF drives green technological innovation. They used enterprise data to analyze the mechanism role of green technology innovation influences CI within DIF [11,12]. Some researchers have gradually begun to adopt a macroeconomic perspective, examining the mediating role of factors such as economic growth and new quality productive forces in the relationship between DIF and CI. Their findings consistently confirm that DIF can effectively curb CI through a series of intermediary factors [13,14].

In summary, scholars have continuously refined research perspectives on the impacts of DIF. Research on the role of industrial structure upgrading (ISU) and household consumption level (HCL) in the relationship still has room for improvement. Previous studies have confirmed that DIF reduces CI through ISU, yet they only examined ISU as a single mediator without incorporating variables related to HCL [15,16]. Other papers have investigated the nexus between DIF and carbon emission efficiency, but the mechanism variables did not involve the dimension of HCL [17]. Although some scholars have taken both ISU and HCL as research objects, their focus was on economic growth and did not extend to the field of CI [18,19]. This study utilizes data from 233 prefecture-level cities in China to investigate the impact of DIF on CI and constructs a mediation model to explore the effects of ISU and HCL in this process. Additionally, this study aims to examine the underlying mechanisms through which DIF influences CI from the perspectives of production and consumption and provides new empirical evidence for understanding how innovations in financial services can jointly boost economic growth and climate governance, thereby contributing to the achievement of the SDGs.

2. Literature Review and Research Hypotheses

2.1. Digital Inclusive Finance and Carbon Emission Intensity

DIF leverages the advantages of digital technology to improve financial service models, effectively enhancing the efficiency of fund allocation [20]. This approach overcomes the constraints of traditional financial services in terms of geographical coverage, access barriers and risk management costs [21]. It incorporates SMEs and entities in remote areas in which traditional financial systems struggle to support the service network, thus alleviating the financing constraints faced by these economic entities. Consequently, DIF not only provides stable financial support for green infrastructure development and clean energy production, but also promotes economic transformation, reducing the carbon emissions associated with increases in gross domestic product (GDP) [22].

As the economy continues to grow, regional industrial clusters are emerging, and infrastructure is gradually delivering economies of scale. DIF facilitates the efficient allocation of various factors of production and reduces CI at the regional level [23]. The institutional environment, governance system and regulatory mechanism of DIF will also be continuously improved and optimized along with economic development. Existing research indicates that a sound institutional environment not only strengthens the initiative of regions in utilizing digital technologies to tap into external information and enhances their overall capacity for technological R&D but also provides robust support for the governments in implementing macroeconomic regulation and driving the leap forward in regional green technological innovation [24]. Based on this analysis, Hypothesis H1 is formulated:

H1. *Digital inclusive finance can effectively curb carbon emission intensity.*

2.2. Digital Inclusive Finance, Industrial Structure Upgrading and Carbon Emission Intensity

ISU refers to the evolution of the industrial structure toward a higher level. The process encompasses technological innovation and the optimization of management models, with the aim of enhancing product value and improving the efficiency of resource allocation. At the macro-level, this is reflected in the shift in the drivers of economic growth relying on factor inputs toward innovation reliance [25]. From the perspective of structural change theory, such upgrading fundamentally depends on the efficiency with which the financial system reallocates capital and labor across sectors [26,27].

By leveraging the widespread adoption of digital technology, DIF can pool scattered funds and small amounts of capital within society more efficiently, unlocking significant potential for mobilizing and aggregating social savings [10]. As data analysis capabilities continue to improve, DIF can effectively enhance information gathering and risk identification capabilities, thereby enabling the precise and efficient allocation of funds to quality enterprises. When enterprises with innovative potential yet capital constraints obtain better access to financial services, they will scale up investments in energy saving technologies and process improvements, enabling the economy to break free from energy intensive production modes and expedite ISU [28].

Innovation is the primary driver of economic development [29]. Technological innovation can mitigate the dependence of production on factor inputs and enhance productivity. This enables enterprises to reduce the socially necessary labor time of their products, generate surplus profits, and continuously drive adjustments and transformations in the industrial structure [30]. Compared to large enterprises, SMEs are the driving force behind technological innovation. They focus on a single area of business and are more flexible in pursuing innovation [31]. However, as SMEs are generally small in scale and lack sufficient collateral, it is difficult to accurately assess their actual financial position and creditworthiness. As SMEs require smaller amounts of funding per transaction, it is costly and low yielding for banks and other financial institutions to conduct such business. Consequently, SMEs are at a disadvantage in the allocation of credit resources and find it difficult to secure adequate financial support [32].

The integration of DIF with cutting-edge digital technologies can effectively address this issue. By analyzing business operations and transaction data, it reduces the financial sector's reliance on traditional collateral and reshapes the financing ecosystem for SMEs [33]. The application of blockchain improves transaction transparency and risk control capabilities; DIF not only opens convenient financing channels for SMEs, but also greatly streamlines cumbersome credit procedures and improves the accessibility of funds. This process creates a relatively fair external financing environment for SMEs and promotes the progress of ISU [34].

The structural bonus hypothesis proposes that rational allocation of factor supplies among industrial sectors and coordinated development of all sectors can optimize the industrial structure and boost productivity growth [35,36]. Based on this hypothesis, scholars analyzed the impact of ISU on CI. They pointed out that ISU is a process of transitioning towards low-carbon, which can effectively reduce CI and promote low-carbon development [37]. In terms of the path of ISU, the role of ISU in curbing CI is primarily reflected in two aspects. One aspect of the path is the optimization of the industrial structure, reducing the share of the energy intensive secondary sector and increasing the proportion of the low-carbon tertiary sector. As the industrial structure is upgraded and the modern service sector expands on a large scale, it can replace some energy intensive industrial production activities and reduce carbon emissions [38]. The other pathway is the upgrading of the internal structure of the secondary sector which drives the green transition of traditional energy intensive industries and fosters emerging industries. The expansion of emerging industries can encourage the sector to step up investment in energy saving upgrades and technological innovation, improve energy efficiency, and reduce carbon emissions per unit of output [39]. Based on this analysis, Hypothesis H2 is formulated:

H2. *Industrial structure upgrading exerts a mediating role in the nexus of digital inclusive finance and carbon emission intensity.*

2.3. Digital Inclusive Finance, Household Consumption Level and Carbon Emission Intensity

HCL refers to the per capita expenditure on goods and services purchased and used by permanent residents in markets to directly meet their daily needs. It is a comprehensive indicator of the extent to which residents' needs for survival, development and enjoyment are met through their consumption of goods and services [40]. The permanent income hypothesis suggests that household spending depends on expected income, and liquidity constraints often hinder households' intertemporal consumption. DIF can precisely alleviate the time gap between income and consumption [41]. By lowering the barriers and transaction costs of financial services, it eases the liquidity constraints faced by low-income groups and promotes consumption level [42]. The traditional financial system often relies on physical branches and credit histories, making it difficult for individuals who lack collateral or have unstable incomes to access formal credit. As a result, their spending decisions are constrained by their current cash holdings [43]. DIF utilizes technologies such as mobile payments and online credit to allow users to 'spend now' and 'pay later' within their credit limit. This consumption process enables purchases that would otherwise have been postponed or canceled due to a mismatch between payday and spending needs [44].

The immediacy and convenience of this liquidity support significantly reduce the financing barriers households face when confronted with large or unexpected expenditure, enabling residents to transition their expected future income into current spending and enhance the flexibility of intertemporal consumption [45].

The precautionary savings theory posits that conservative consumers increase their savings to guard against a future decline in their standard of living. The main motivations for saving among this group include maintaining their standard of living in retirement and providing an inheritance for their children [46]. DIF has improved digital access to social security and enhanced the stability of income, thereby reducing the incentive for households to engage in precautionary saving [47]. Rural residents and freelancers face a higher risk of income volatility and pressure from unexpected expenses; they rely on personal savings to cope with uncertainty. But excessive precautionary savings severely crowd out current consumption and reduce the quality of present consumption. The development of DIF has enabled microinsurance and flexible digital wealth management products to reach this demographic efficiently. Residents can purchase health insurance via online application or invest spare funds in low threshold money market funds [48]. When residents have access to more reliable sources of emergency funds, they will reduce the amount of idle savings they set aside specifically to guard against unknown risks [49]. According to the life cycle theory, a decline in precautionary savings is directly equivalent to an increase in disposable income for consumption [50].

Engel's Law reveals the fundamental relationship between income growth and changes in consumption structure: as income levels rise, the proportion of spending on subsistence consumption such as food declines, while the share of spending on service-oriented and development-oriented consumption rises. This law also applies to the current market economy. Once household consumption capacity crosses a specific threshold, their awareness of energy conservation will increase markedly, prompting them to take initiative to optimize consumption structures and choose clean energy sources. Within total household expenditure, the proportion of service-oriented consumption including education, cultural tourism and travel rises significantly, whereas the share of consumption of physical goods and high energy consuming products shows a downward trend [51]. This gradually weakens the positive correlation between economic growth and carbon emissions, ultimately achieving decoupling [52]. Green consumption behavior carries inherent inertia; once formed, it will reinforce itself over the long term and continuously lower emission levels. Moreover, economic prosperity provides fiscal support for environmental regulations, enabling regulatory measures to accelerate the popularization of green consumption once they reach an intensity threshold [53,54].

From a production perspective, an increase in consumption does not necessarily lead to a proportional rise in energy demand [55]. The demand-induced innovation theory states that the expansion of scale of consumer demand can incentivize enterprises to pursue technological innovation and product upgrading through market scale effects and competitive pressures [56]. As an increasing number of consumers direct their purchasing power toward products and services with stronger low-carbon attributes, producers must proactively adjust their production structures and accelerate the phasing out of energy intensively to obtain consumer recognition in the competitive market [57]. The continued growth in demand for green products provides businesses with clear market signals, transforming the low-carbon transition from an externally driven policy constraint into an internally driven pursuit of profit. This transformation of the supply system, driven by green preferences on the demand side, has enabled the economy to achieve a sustained reduction in carbon intensity against a backdrop of expanding output [58]. The improvement of residents' purchasing power has increased their willingness to pay for better housing standards and public services. This willingness to pay helps to drive the development of urban green infrastructure and the overall optimization of energy systems and creates a virtuous cycle of reduced CI at a broader level [59]. Based on this analysis, Hypothesis H3 is formulated:

H3. *Household consumption level exerts a mediating role in the nexus of digital inclusive finance and carbon emission intensity.*

3. Research Design

3.1. Sample and Data

The year 2015 marked a critical turning point when China's DIF shifted from rapid expansion to standardized development. The State Council issued the Plan for Promoting the Development of Inclusive Finance (2016–2020), ushering in a new phase for the growth of DIF. DIF formats represented by mobile payment and online credit entered a period of vigorous development. Taking 2015 as the starting point helps to explore the systematic impacts of DIF on CI.

The data were sourced from the Emissions Database for Global Atmospheric Research (EDGAR), the China Statistical Yearbook, and the Peking University Digital Inclusive Finance Index. Considering the requirements for sample size and data availability, this study selects prefecture-level cities across China as research subjects. To guarantee the integrity and temporal continuity of panel data, we exclude cities in Xinjiang, Xizang and other regions with severe statistical missing values, as well as all other cities featuring incomplete variables. Finally, a total of 233 valid prefecture-level city samples are obtained.

3.2. Definition of Variables

3.2.1. Explanatory Variable

This paper uses the logarithm of the China Digital Finance Index compiled by the center of digital finance at Peking University to assess the level of development of DIF in prefecture-level cities [60]. As Peking University's digital finance data are only available up to 2023, the 2024 DIF index has been estimated using a moving average method [61].

3.2.2. Explained Variable

CI refers to the amount of carbon dioxide emitted per unit of gross domestic product. The lower a city's CI, the fewer carbon emissions it generates whilst creating a given amount of economic value, indicating a greener and low-carbon economic structure [62]. Table 1 illustrates the measurement method of CI.

Table 1. Variable definitions.

Type	Variables	Symbol	Measurement
Explanatory Variable	Digital inclusive finance	DIF	Peking University digital inclusive finance index
Explained variable	Carbon emission intensity	CI	Ln (Carbon dioxide emissions/GDP)
Mediating variables	Industrial structure upgrading	ISU	Proportion of added value of the primary industry in GDP $\times$ 1 + Proportion of added value of the secondary industry in GDP $\times$ 2 + Proportion of added value of the tertiary industry in GDP $\times$ 3
	Household consumption level	HCL	Per capita consumption expenditure

Table 1. *Cont.*

Type	Variables	Symbol	Measurement
Control variables	Population size	POP	Ln (Permanent population)
	Industrial structure	IS	Value added in the tertiary sector/GDP
	Human capital	HC	Number of students enrolled in institutions of higher education/Total population at year-end
	Financial development	FD	Loan balance of financial institutions/GDP
	Technological development	TD	Expenditure on science and technology/General local fiscal expenditure
	Pressure from fiscal imbalance	PFI	(General budget fiscal expenditure—General budget fiscal revenue)/GDP
	Degree of government intervention	GI	General budget expenditure/GDP

3.2.3. Mediating Variables

Drawing on the research findings of Hou Jianming, this paper uses the share of output value from each industrial sector in gross domestic product to calculate an ISU index [63]. The specific calculation formula is shown in Table 1.

Per capita consumption expenditure refers to the cash and in-kind expenditures made by residents for daily living consumption, reflecting residents' consumption capacity and willingness. Using the logarithm of per capita consumption expenditure to measure HCL can objectively reflect residents' actual consumption potential and quality of life [64].

3.2.4. Control Variables

Based on previous studies [65,66], this paper selects seven control variables: population size, industrial structure, human capital, financial development, technological development, pressure from fiscal imbalance, and degree of government intervention. A larger population size leads to higher energy consumption and carbon emissions from daily production and living activities. Industries vary considerably in pollutant discharge and energy consumption, and the layout of the industrial structure profoundly affects CI. A high-quality labor force facilitates the application of low-carbon technologies and promotes the development of low-carbon production modes. The flow of regional financial resources influences the cultivation of green industries and impact CI. More advanced urban production technologies help optimize production processes and reduce carbon emissions per unit of output. Local government fiscal capacity determines investment in environmental protection and affects the progress of regional carbon emission reduction governance. Administrative regulation by governments serves as a crucial restraint on corporate pollutant discharge and exerts a substantial influence on the overall CI trend. The above control variables exert certain impacts on the development level of the core variables from different perspectives such as labor factors, production levels and macro-control. After controlling their fixed effects, we can more accurately test the net effect of DIF on CI and reduce estimation bias. The specific variables' definition and measurement methods are summarized in Table 1.

https://doi.org/10.3390/su18136666

3.2.5. Model Specification

To examine the impact of DIF on CI, we construct the following regression model:

$$CI_{it} = \alpha_0 + \alpha_1 \mathrm{DIF}_{it} + \alpha_2 X_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (1)$$

$$ISU_{it}/HCL_{it} = \beta_0 + \beta_1 \mathrm{DIF}_{it} + \beta_2 X_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (2)$$

$$CI_{it} = \gamma_0 + \gamma_1 \mathrm{DIF}_{it} + \gamma_2 ISU_{it}/\gamma_2 HCL_{it} + \gamma_3 X_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (3)$$

In this context, the subscripts i and t in Equation (1) denote the province and the year. CI_{it} is the dependent variable, representing the CI of City i in year t. The explanatory variable DIF_{it} represents the level of DIF in City i in year t. X_{it} indicates the control group, μ_i represents the city fixed effect, σ_t represents the time fixed effect, ε_{it} is the random disturbance term, and all other variables are parameters to be estimated. ISU and HCL are mechanism variables. γ_1 is the core coefficient focused on in this paper, which explains the impact of DIF on CI.

4. Empirical Results

4.1. Descriptive Statistics

Descriptive statistics for the variables are presented in Table 2. The maximum and minimum value for CI is 2.076 and −1.723, indicating significant differences in CI between cities. The maximum value for DIF is 5.831, and the median is 5.533, suggesting that the level of development of DIF is generally balanced across cities. The median and mean values for ISU and HCL are close to one another, suggesting that the development of both indicators is relatively stable. The mean values of each control variable are 5.952, 0.482, 0.021, 2.900, 0.020, 0.127 and 0.203 respectively. Comparing the maximum values and standard deviations of the control variables reveals significant individual differences among the sample cities.

Table 2. Results of descriptive statistics.

Variables	N	Mean	SD	Min	Max	Median
DIF	2330	5.503	0.191	5.038	5.831	5.533
CI	2330	0.116	0.814	−1.723	2.076	0.062
ISU	2330	2.370	0.120	1.924	2.850	2.361
HCL	2330	10.516	0.281	9.759	11.416	10.498
POP	2330	5.952	0.703	3.302	8.075	5.980
IS	2330	0.482	0.083	0.227	0.853	0.477
HC	2330	0.021	0.020	0.002	0.093	0.014
FD	2330	2.900	1.145	1.295	6.929	2.598
TD	2330	0.020	0.018	0.001	0.092	0.014
PFI	2330	0.127	0.095	0.003	0.693	0.102
GI	2330	0.203	0.093	0.059	0.745	0.178

4.2. Multicollinearity Test

To mitigate the risk that residual multicollinearity in the model might compromise the accuracy of the parameter estimates, a variance inflation factor (VIF) multicollinearity test across all variables was carried out before the baseline regression. The VIF values of the variables range from 1.50 (POP) to 7.99 (PFI). According to the existing literature, a VIF value below 10 indicates that severe multicollinearity is not a concern among the variables [67,68]. It can be concluded that the variables selected in this study do not exhibit severe multicollinearity, and the model specification is deemed appropriate for subsequent empirical analysis.

https://doi.org/10.3390/su18136666

4.3. Benchmark Regression

As reported in Table 3, only city and time fixed effects are controlled, the regression coefficient of the independent variable in column (2) is −0.649, which is significant at the 5% level. Following the inclusion of the full set of control variables, the independent variable's coefficient retains a significantly negative sign, revealing that the growth of DIF exerts a potent inhibitory effect on CI. DIF leans toward the clean energy sector, facilitates the gradual transformation of traditional industries that consume large amounts of energy, and reduces carbon emissions generated by fossil energy consumption. Finance guides the aggregation of industrial resources, promotes the optimization of regional industrial structures, and limits the development space of industries with high carbon emissions. The coordinated effect of multiple mechanisms continuously optimizes production and development modes, bringing about a steady decline in regional CI.

Table 3. Benchmark regression results.

Variables	**(1)**	**(2)**	**(3)**	**(4)**
	CI	**CI**	**CI**	**CI**
DIF	−1.030 ***	−0.694 **	−0.317 ***	−0.641 **
	(−12.02)	(−2.05)	(−3.17)	(−2.15)
POP			−0.304 ***	−0.680 ***
			(−12.02)	(−4.12)
IS			−1.823 ***	−0.511 **
			(−6.63)	(−2.11)
HC			−1.220	1.002
			(−1.14)	(0.95)
FD			0.044 **	0.039 **
			(2.07)	(2.05)
TD			−8.619 ***	−1.262 **
			(−8.29)	(−1.98)
PFI			−5.194 ***	1.564 **
			(−7.02)	(2.30)
GI			4.987 ***	0.279
			(6.35)	(0.44)
_cons	5.783 ***	3.933 **	4.263 ***	7.575 ***
	(12.26)	(2.12)	(7.28)	(3.71)
Year	NO	YES	NO	YES
City	NO	YES	NO	YES
N	2330	2330	2330	2330
Within R^2	0.058	0.009	0.233	0.133

Note: *** $p < 0.01$, ** $p < 0.05$.

4.4. Mediation Effect Analysis

Table 4 reports the regression outcomes of DIF on the mediating variables in Columns (1) and (3). Their regression coefficients are significantly positive at the 1% level, indicating that DIF can promote ISU and raise HCL. Column (2) reports the regression result of DIF on CI after incorporating ISU; the coefficient is also negative at the 1% significance level. The indirect effect coefficient obtained via Bootstrap test is −0.108, and the corresponding confidence interval does not contain 0. Column (4) displays the regression result of DIF on CI after adding HCL. The result was statistically significant, with an indirect effect coefficient of −0.134 and a confidence interval that did not include 0. The results indicate that ISU and HCL serve as mediating channels along the transmission path, and the profile effect contribution rates are 16.78% and 20.93% respectively. On the one hand, HCL tightens credit supply for high energy consuming industries, guides the reallocation of industrial resources, and cuts carbon emissions from the production side. On the other hand, it expands income sources, compels enterprises to innovate in production modes, and facilitates effective control over overall carbon emissions.

Table 4. Mediation effect analysis results.

Variables	(1)	(2)	(3)	(4)
	ISU	**CI**	**HCL**	**CI**
DIF	0.052 ***	−0.534 ***	0.543 ***	−0.507 ***
	(4.09)	(−2.81)	(5.88)	(−2.69)
ISU		−2.063 ***		
		(−6.09)		
HCL				−0.247 ***
				(−4.79)
POP	0.030 ***	−0.618 ***	0.274 ***	−0.612 ***
	(4.78)	(−7.26)	(5.55)	(−6.92)
IS	1.065 ***	1.687 ***	0.333 ***	−0.429 ***
	(12.82)	(4.36)	(5.22)	(−3.18)
HC	0.065	1.137 *	−0.103	0.977
	(1.02)	(1.93)	(−0.22)	(1.60)
FD	−0.002 *	0.036 ***	0.003	0.040 ***
	(−1.67)	(2.73)	(0.39)	(2.97)
TD	0.009	−1.243 ***	0.646 ***	−1.102 ***
	(0.35)	(−3.33)	(2.83)	(−2.95)
PFI	−0.009	1.544 ***	0.306 *	1.639 ***
	(−0.34)	(3.90)	(1.75)	(4.13)
GI	−0.060 **	0.156	−0.510 ***	0.153
	(−2.55)	(0.42)	(−3.03)	(0.41)
_cons	1.405 ***	10.474 ***	5.775 ***	9.001 ***
	(16.35)	(7.55)	(8.78)	(6.93)
Year	YES	YES	YES	YES
City	YES	YES	YES	YES
Bootstrap	[−0.173, −0.142]		[−0.209, −0.060]	
p	0.000		0.000	
N	2330	2330	2330	2330
Within R^2	0.897	0.133	0.065	0.133

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.5. Robustness Test

4.5.1. Changing the Explanatory Variable

The DIF coverage index focuses on the breadth and reach of financial services and thus provides a more intuitive illustration of the emissions reduction effects resulting from the expansion of DIF [69]. Column (1) of Table 5 presents the test results, which show that DIF continues to have a significant mitigating effect on CI, thereby reinforcing the robustness of the study's conclusions.

Table 5. Results of robustness tests.

Variables	(1)	(2)	(3)	(4)	(5)
	CI	**CI**	**CI**	**CI**	**CI**
DIF	−0.508 **	−0.010 *	−0.725 **	−0.604 **	−0.605 **
	(−2.33)	(−1.80)	(−2.37)	(−2.30)	(−2.09)
POP	−0.804 ***	−0.029 ***	−0.672 ***	−0.558 ***	−0.676 ***
	(−4.47)	(−8.32)	(−4.06)	(−3.49)	(−4.11)

https://doi.org/10.3390/su18136666

Table 5. *Cont.*

Variables	(1)	(2)	(3)	(4)	(5)
	CI	CI	CI	CI	CI
IS	−0.479 *	−0.004	−0.509 **	−0.277	−0.548 **
	(−1.97)	(−0.73)	(−2.10)	(−1.15)	(−2.09)
HC	0.854	0.019	0.868	1.008	1.204
	(0.80)	(0.94)	(0.81)	(0.97)	(0.98)
FD	0.036 *	0.004 **	0.037 **	0.032 *	0.065 ***
	(1.96)	(2.30)	(1.98)	(1.79)	(2.94)
TD	−1.274 **	0.005	−1.114 *	−0.887	−1.433 **
	(−2.02)	(0.86)	(−1.75)	(−1.36)	(−2.32)
PFI	1.525 **	−0.008 *	1.384 **	1.381 *	1.763 **
	(2.23)	(−1.96)	(2.06)	(1.95)	(2.59)
GI	0.236	0.007 *	0.458	0.330	−0.100
	(0.37)	(1.70)	(0.73)	(0.50)	(−0.15)
_cons	7.590 ***	0.252 ***	7.968 ***	6.528 ***	7.355 ***
	(3.99)	(5.57)	(3.82)	(3.63)	(3.68)
Year	YES	YES	YES	YES	YES
City	YES	YES	YES	YES	YES
N	2330	2330	2290	2097	2097
Within R^2	0.136	0.479	0.139	0.110	0.137

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.5.2. Changing the Explained Variable

Per capita carbon emissions can reflect the actual regional carbon emission levels from an individual perspective. To further improve the reliability of research conclusions, per capita carbon emissions are selected to replace CI for testing, and the result is shown in Column (2). After replacing the explained variable, the regression results pass the significance test, which verifies the robustness of the research conclusions.

4.5.3. Excluding Municipalities

Municipalities directly under the central government, such as Beijing, Shanghai, Tianjin and Chongqing, possess unique advantages in terms of economic development, digital infrastructure development and the vigor of policy implementation. Their governance models differ from those of ordinary cities, and the carbon emission control systems also exhibit distinct characteristics. To prevent specific cities from skewing the overall regression results, the study excluded the above four cities and performed the regression analysis again. As shown in column (3), after controlling estimation biases arising from regional differences, the relationship between DIF and CI passes the significance test.

4.5.4. Changing the Observation Window

It takes a certain period for DIF to exert emission reduction effects through approaches such as technological empowerment and resource optimization. To mitigate cointegration bias, the explanatory variable is lagged for one period. The test results reveal that the inhibitory effect of DIF on CI remains valid.

4.5.5. Excluding Special Samples

This paper adopts the moving average approach to compute the 2024 DIF, which may induce bias in the empirical estimations. We excluded the 2024 sample for robustness testing. The results in Column (5) show that the inhibitory effect of DIF on CI remains significant, which indicates that the measurement results derived from the moving average method do not alter the research conclusions of this paper.

4.6. Endogeneity Test

Drawing on existing research, this study uses the mean value of DIF of other cities in the same province and year as the instrumental variable (IV) [70]. The spillover effects generated by DIF development in other cities exert an influence on the local city to a certain extent, satisfying the correlation of the instrumental variables. There is no direct correlation between the level of DIF development in other cities and this city's CI, satisfying the exclusivity requirement. The test results are shown in Table 6. In the first stage, the F-value is greater than 10, as confirmed by the instrumental variables test. The p-value for the Kleibergen–Paap rk LM statistic is close to 0, and the Cragg–Donald Wald F-statistic exceeds the 10% significance threshold of the Stock–Yogo weak identification test by 16.38. The regression coefficient for IV relative to the dependent variable is −1.267, and this passes the significance test at the 5% level. The results indicate that, even after controlling endogeneity bias, DIF continues to have a mitigating effect on CI.

Table 6. Results of the endogeneity test.

Variables	(1)	(2)	(3)	(4)	(5)
	IV				GMM
	DIF	CI	DIF	CI	CI
L. CI					0.484 **
					(2.58)
IV	0.736 ***		0.401 ***		
	(16.56)		(12.29)		
DIF		−1.267 **		−1.506 **	−0.395 **
		(−2.14)		(−2.37)	(−2.09)
POP	−0.115 ***	−0.738 ***	−0.040 ***	−0.618 ***	−0.612 **
	(−6.05)	(−4.35)	(−3.35)	(−3.78)	(−2.54)
IS	0.014	−0.467 *	−0.013	−0.297	−0.432 *
	(0.68)	(−1.86)	(−0.97)	(−1.21)	(−1.77)
HC	−0.354 **	0.789	−0.134 **	0.807	2.998
	(−2.29)	(0.69)	(−2.02)	(0.75)	(1.40)
FD	0.002	0.040 **	0.001	0.032 *	0.151 ***
	(0.95)	(2.12)	(0.12)	(1.79)	(2.82)
TD	0.076	−1.098 *	0.113 **	−0.716	1.040
	(1.09)	(−1.70)	(2.52)	(−1.07)	(0.70)
PFI	−0.174 ***	1.441 **	−0.137 ***	1.175	−1.820 ***
	(−2.84)	(2.15)	(−2.86)	(1.64)	(−2.87)
GI	0.099 *	0.340	0.095 **	0.473	1.481 ***
	(1.65)	(0.54)	(2.03)	(0.71)	(3.97)
Year	YES	YES	YES	YES	YES
City	YES	YES	YES	YES	YES
LM statistic	81.174 ***		72.459 ***		
F statistic	810.970 ***		151.142 ***		
N	2330	2330	2097	2097	2097

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

This paper further adopts the system generalized method of moments (GMM) and lags the explanatory variables by one period to address endogeneity issues. As shown in Columns (3) and (4), the lagged term of DIF satisfies the test criteria for instrumental variables, and the regression results confirm that the inhibitory effect of DIF on CI remains valid. The p-values of AR (2) and Hansen are both greater than 0.1, which indicates that the endogeneity problem of the model constructed in this paper is well controlled. After controlling endogeneity, the coefficient of DIF is −0.395 and significantly negative at the 5%

significance level, revealing that DIF significantly reduces CI and there is no severe reverse causality in this research.

4.7. Heterogeneity Analysis

4.7.1. Heterogeneity Analysis of Different Quantiles

To reveal the heterogeneous impacts of DIF under different CI, this study employs panel quantile regression [71]. The results are presented in Table 7. At the 0.25, 0.50 and 0.75 percentile levels, the estimated coefficients for DIF all passed the 1% significance test. The findings indicate that as urban carbon emissions rise, the development of DIF offers a clear comparative advantage in curbing CI. In these cities, DIF can more effectively drive technological progress and support producers in adopting more advanced production techniques and management methods. DIF helps to reduce CI by alleviating information asymmetries, channeling funds towards the low energy consumption stages of production, and optimizing resource allocation, thereby reducing waste and inefficient energy consumption.

Table 7. Results of panel quantile regression.

Variables	(1)	(2)	(3)
	25%CI	**50%CI**	**75%CI**
DIF	−0.484 ***	−0.492 ***	−0.543 ***
	(−10.09)	(−3.53)	(−18.14)
POP	−0.205 ***	−0.207 ***	−0.516 ***
	(−8.37)	(−3.05)	(−63.72)
IS	−1.777 ***	−0.981 *	−0.557 ***
	(−6.52)	(−1.81)	(−5.37)
HC	−2.092 ***	1.921	1.870 ***
	(−10.58)	(0.96)	(7.37)
FD	0.010	0.009	0.022 **
	(1.07)	(0.25)	(2.33)
TD	−4.970 ***	−3.116 **	−2.442 ***
	(−7.07)	(−2.15)	(−3.99)
PFI	−2.008 ***	0.778	−1.871 ***
	(−5.35)	(0.91)	(−6.08)
GI	2.049 ***	0.326	2.433 ***
	(6.67)	(0.42)	(8.30)
Year	YES	YES	YES
City	YES	YES	YES
N	2330	2330	2330

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The findings reveal that the mitigating effect of DIF holds under contextual constraints. On the one hand, it is constrained by the maturity of DIF development. When the development level of DIF is relatively low, the insufficient supply of financial resources makes it difficult to fully leverage investment in low-carbon transition. On the other hand, the effect depends on the interval of the city's own CI. When a city has a low CI, the inhibitory effect generated by DIF is relatively weak.

4.7.2. Heterogeneity Analysis of Environmental Protection

Based on policy objectives and development practices relating to urban environmental protection, the study categorizes the sample into two groups according to whether the cities are designated as environmental protection cities. In the sample of environmentally protection cities, the regression coefficient for DIF is −1.288, and it passed the test for statistical significance. In cities committed to environmental protection, the manufacturing sector faces strict emission reduction targets, which make them more willing to undertake energy saving upgrades. DIF can precisely address the needs of businesses undergoing a green transition, providing convenient financial support to enhance energy efficiency in production processes. On the consumer side, by leveraging green consumption scenarios and policy guidance, DIF can lower the barriers to green consumption for households through products such as green consumer loans and payment incentives, creating a pull for emissions reductions from the demand side.

4.7.3. Heterogeneity Analysis of Urban Positioning

The study conducted a regression analysis after matching the research sample with the 'central cities' mentioned in the State Council's approval documents for the 'Master Plans for Territorial Space' of various cities. In column (4) of Table 8, the regression coefficient of DIF in non-central cities is −0.706, which passes the significance test. For non-central cities, the advantages of the wide coverage and low entry barriers of DIF can effectively reach SMEs that are hard to cover by traditional finance. They can provide funding to support these enterprises in upgrading their equipment and improving production efficiency. Conversely, in central cities with more mature governance systems and financial resources, energy efficiency and emission reduction levels have already reached a plateau, and the marginal benefits of further emission reductions are relatively limited.

Table 8. Results of the heterogeneity analysis.

Variables	**(1)** **CI**	**(2)** **CI**	**(3)** **CI**	**(4)** **CI**
DIF	−1.288 ***	−0.482	−0.897	−0.706 **
	(−2.85)	(−1.30)	(−1.01)	(−2.09)
POP	−1.134 ***	−0.263	−1.323 ***	−0.443 *
	(−5.89)	(−0.79)	(−3.34)	(−1.86)
IS	0.232	−0.725 ***	−0.162	−0.505 **
	(0.48)	(−2.96)	(−0.21)	(−2.06)
HC	−0.799	1.307	−1.601	1.740
	(−0.64)	(0.77)	(−0.67)	(1.48)
FD	0.028	0.034	−0.001	0.047 **
	(1.01)	(1.32)	(−0.05)	(1.99)
TD	−2.345 ***	0.187	−1.539	−1.034
	(−3.71)	(0.16)	(−1.44)	(−1.37)
PFI	1.604	1.596 *	1.237	1.435 **
	(1.33)	(1.91)	(0.70)	(1.98)
GI	0.331	0.273	0.284	0.367
	(0.31)	(0.34)	(0.17)	(0.54)
_cons	13.987 ***	4.226	13.729 **	6.487 ***
	(5.05)	(1.62)	(2.62)	(2.84)
Year	YES	YES	YES	YES
City	YES	YES	YES	YES
N	930	1400	290	2040
Within R^2	0.223	0.123	0.318	0.124

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.7.4. Heterogeneity Analysis of Different Dimensions

The three secondary indicators of DIF, namely coverage breadth (CB), usage depth (UD) and digitalization level (DL), are taken as explanatory variables to examine the heterogeneous impacts on CI, and the regression results are shown in Table 9. The study finds that the coefficient of UD fails to pass the significance test. The limited effectiveness of usage depth stems from the insufficient popularization of DIF in some regions, as enterprises and individuals lack adequate awareness and operational capabilities regarding relevant products and services. For instance, some enterprises are unfamiliar with the application procedures of green financial products and thus cannot effectively leverage such tools to achieve energy conservation.

Table 9. Results of heterogeneity test in different dimensions.

Variables	(1) CI	(2) CI	(3) CI
CB	−0.508 **		
	(−2.33)		
UD		0.001	
		(0.47)	
DL			−0.001 ***
			(−3.48)
POP	−0.804 ***	−0.636 ***	−0.509 ***
	(−4.47)	(−3.83)	(−3.08)
IS	−0.479 *	−0.557 **	−0.535 **
	(−1.97)	(−2.34)	(−2.29)
HC	0.854	1.248	1.143
	(0.80)	(1.21)	(1.12)
FD	0.036 *	0.038 *	0.049 **
	(1.96)	(1.95)	(2.50)
TD	−1.274 **	−1.445 **	−1.214 *
	(−2.02)	(−2.28)	(−1.89)
PFI	1.525 **	1.694 **	1.741 **
	(2.23)	(2.43)	(2.55)
GI	0.236	0.207	0.196
	(0.37)	(0.32)	(0.31)
_cons	7.590 ***	3.696 ***	3.415 ***
	(3.99)	(3.75)	(3.54)
N	2330	2330	2330
Within R^2	0.136	0.127	0.142

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.8. Spatial Spillover Analysis

To further investigate the spatial impact of DIF on CI, the spatial spillover effect is analyzed. The spatial Durbin model with fixed effects is adopted based on LM, LR and Wald tests. The results are presented in Table 10. The spatial autoregressive coefficient is significant at the 1% level, indicating that DIF presents spatial spillover characteristics. Meanwhile, the indirect estimated coefficient is significantly positive, which means that while urban DIF curbs CI, it boosts the CI of neighboring cities.

Table 10. Results of spatial spillover analysis.

Variables	CI	Direct Effect	Indirect Effect
DIF	−0.558 *** (−3.39)	−0.502 *** (−3.07)	1.796 ** (2.43)
W × DIF	1.1701 *** (2.823)		
Controls	YES	YES	YES
Year	YES	YES	YES

Table 10. *Cont.*

Variables	CI	Direct Effect	Indirect Effect
City	YES	YES	YES
rho	0.496 *** (12.10)		
N	2330		
R^2	0.236		

Note: *** $p < 0.01$, ** $p < 0.05$.

It is worth noting that this result reflects the status of the sample within the currently selected time and does not contradict the previous results. The causes of this phenomenon can be analyzed from the following aspects: The inclusiveness of DIF manifests on the demand side, implying that DIF prioritizes meeting local financial demands during its development and highlights intra-regional integration. From the perspective of financial agglomeration, given the imperfect credit market, the financial industry displays a strong home bias in capital allocation, and financial agglomeration has a geographical attenuation boundary, which restricts the radiation effect of financial centers on surrounding areas. Local regions attract capital and talents from neighboring areas by virtue of superior financial resources, which may drive high energy consumption and high polluting industries to relocate to adjacent regions with loose regulatory standards, thereby increasing carbon emissions in neighboring areas [72].

This demonstrates that from an overall regional perspective, the carbon emission reduction benefits of current DIF are confined within administrative boundaries, failing to achieve cross-regional collaborative emission reduction; instead, a periodic spatial pattern of "shifting harms to neighbors" has emerged.

5. Conclusions and Recommendations

5.1. Conclusions

Drawing on data from 233 prefecture-level cities spanning 2015–2024, this paper examines the impact of DIF on urban CI and its underlying mechanisms. Empirical findings indicate that DIF can curb CI. From the perspective of action paths, DIF achieves carbon emission reduction through two paths: production and consumption. On the production side, it has eased financing constraints for SMEs and promoted the upgrading of the industrial structure towards higher value sectors. On the consumer side, it eases residents' liquidity constraints, reduces their incentive for precautionary savings, and guides their demand to shift toward green development. Furthermore, the mitigating effect of DIF on CI is more pronounced in cities with higher carbon intensity, as well as in environmental protection cities and non-central cities.

This finding also echoes the principle of "common but differentiated responsibilities" in sustainable development, which means differentiated financial support schemes should be formulated considering the initial conditions and institutional environments of different regions so that limited financial resources can deliver the greatest environmental benefits in the most needed areas. From a broader perspective, this study offers a lens for understanding the interactive relationship between digital technology, financial development and environmental governance, and provides methodological references for subsequent research to explore the role of DIF in a wider range of sustainability issues.

5.2. Policy Implications

Cities with high CI should leverage the carbon reduction leverage effect of DIF. Such cities feature a high proportion of traditional industries and greater marginal room for emission cuts. It is recommended that regulatory authorities channel DIF resources toward the green transformation links of high carbon industries. For instance, special digital credit products can be offered for energy-saving technological transformation projects in sectors including steel, chemical engineering and materials. Big data can also be adopted to dynamically monitor enterprises' energy consumption and emission reduction performance, with loan interest rates linked to actual carbon reduction outcomes. A risk compensation fund for DIF in high carbon cities may be established to share a certain proportion of risks arising from green transformation loans issued by financial institutions to high carbon enterprises, to incentivize the financial supply side to voluntarily offer favorable terms, and to conduct targeted fund allocation.

Cities with a high level of environmental governance have residents with strong green awareness, while their manufacturing industries are also subject to stringent emission reduction constraints. It is recommended that such cities leverage mobile payment and digital credit platforms to convert residents' green behaviors (such as taking public transport and participating in waste sorting) into quantifiable carbon points, which can be linked to financial benefits including credit lines and consumption discounts. Financial institutions should be encouraged to cooperate with local governments to launch special credit products for green consumption, lowering the financing threshold for households purchasing energy saving equipment and other products to drive the green transformation on the supply side from the demand side.

Non-central cities should prioritize addressing the insufficient depth of DIF coverage. Such cities generally lack branch networks of large financial institutions, resulting in a limited reach of traditional financial services. It is recommended that financial regulatory authorities coordinate the development of a unified regional credit information platform to cut customer acquisition and risk control costs for financial institutions. Local governments set up special interest discount funds for green transformation to provide loan interest discount support for SMEs carrying out energy conservation and grant additional points in macro-prudential assessment to outstanding financial institutions.

The coordinated development of DIF also constitutes an indispensable component. For DIF, the coordinated advancement of CB, UD and DL is required to maximize its overall effects. Neighboring regions should establish multi-channel communication mechanisms to advance the coordinated development of regional DIF, mitigate the pollution effect, and reduce CI from an aggregate perspective.

5.3. Limitations and Future Research

This paper highlights that DIF can boost the CI of neighboring regions. However, due to limitations regarding the research period and sample size, the findings may fail to accurately reflect the conditions of all cities nationwide. Future research should expand the time frame and sample coverage to more precisely capture the nationwide situation and the underlying root causes behind such phenomena. The effect of DIF on CI is subject to certain boundary conditions. Although a brief analysis of such boundary conditions has been conducted through heterogeneity analysis, future research should further examine specific boundary effects or explore whether there exists a nonlinear relationship between DIF and CI. The estimated coefficient for the control variable FD is positive, whereas that for GI appears relatively unstable. Follow-up research will explore the correlation between these two variables and CI, as well as the underlying causes of this phenomenon. Finally, there still exists a certain degree of controversy regarding the relationship between consumption and carbon emissions. Future research can draw on the conclusions of this paper to analyze whether the growth of consumption capacity boosts carbon emission volume or contributes to carbon emission decoupling.

Author Contributions: Conceptualization, L.X. and X.M.; methodology and analysis, L.X.; writing—original draft preparation, X.M.; writing—review and editing, L.X. All authors have read and agreed to the published version of the manuscript.

Funding: This paper was funded by the Major Humanities and Social Science Research Project of Anhui Provincial Department of Education: Dynamic Transformation and Path Optimization of High-quality Development of Manufacturing Industry in the Wanjiang Area Under the Background of Digital Transformation (Grant No. 2025AHGXSK20004).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study is available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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https://doi.org/10.3390/su18136666