

The Impact of Digital Inclusive Finance on Urban Carbon Emission Efficiency: Evidence from China

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Abstract: This research explores the role of digital inclusive finance in improving urban carbon emission efficiency, based on data from 282 prefecture-level cities in China and using a fixed-effects model. The analysis shows that digital finance positively impacts carbon efficiency, with significant regional differences. The effect is more pronounced in the eastern region, attributed to its advanced development level. Among the various aspects of digital finance, broader accessibility exerts a stronger influence on carbon efficiency than service diversification. Furthermore, digital finance drives green technological innovation, which further enhances urban carbon efficiency. The study emphasizes the importance of increasing access to digital finance in less developed areas and leveraging financial platforms to encourage green innovation, contributing to sustainable urban development and carbon reduction.

Keywords: Digital inclusive finance, carbon emissions, carbon emission efficiency, sustainability.

1. Introduction

Digital inclusive finance utilizes advanced technologies to improve the accessibility, convenience, and efficiency of financial services, addressing the financial needs of various social groups [1]. In China, the rapid advancement and adoption of digital technology have fueled the growth of digital inclusive finance, positioning it as a crucial driver of inclusive finance development [2]. This growth not only addresses issues like information asymmetry, reduces service costs, and enhances efficiency but also promotes financial innovation and supports economic transformation.

As global climate challenges intensify, reducing greenhouse gas emissions and improving carbon efficiency have become shared global priorities. China, as the largest developing country, faces significant pressure to cut emissions while pursuing high-quality economic growth. To address this, the Chinese government has advanced "dual carbon" goals—carbon peaking and carbon neutrality—by promoting green economic and societal transformation through technological innovation and policy measures [3]. Against this backdrop, digital inclusive finance has become a focal point of research for its potential impact on urban carbon emission efficiency [4].

The influence of digital inclusive finance on carbon efficiency is multifaceted. On the positive side, it fosters economic restructuring, supports green industry growth, and reduces reliance on high-carbon sectors, thereby enhancing carbon efficiency [5-7]. However, it also has drawbacks, such as

increased energy consumption from digital technologies and emissions from data centers, which may negatively affect carbon efficiency [8, 9].

Investigating this impact offers important insights into the functioning of digital inclusive finance and its role in shaping effective carbon reduction strategies. This research analyzes the connection between digital inclusive finance and urban carbon emission efficiency in Chinese prefecture-level cities, providing a valuable reference for promoting China's carbon reduction efforts.

2. Literature Review

2.1. Carbon Emission Efficiency

Carbon emission efficiency plays a vital role in environmental research, particularly in tackling climate change. Previous studies have examined its various aspects, including measurement methods, influencing factors, and spatial-temporal dynamics. The significance of single-factor indicators such as carbon production efficiency and carbon intensity for performance evaluation has been highlighted [10]. Carbon emission efficiency has been defined as the ratio between economic output and carbon emissions, emphasizing the goal of maximizing economic output while reducing emissions [11]. It is also described as the proportional relationship between carbon emissions, economic growth, and energy use [12].

The beneficial impact of green energy and innovative technologies in enhancing carbon emission efficiency has been emphasized [13]. The critical role of improving CO₂ efficiency to support low-carbon development goals has been underscored [14]. Factors such as urbanization rate, energy structure, and technological progress have been identified as major drivers of carbon efficiency in China [15]. The combined effects of digital finance and green technological innovation in boosting carbon emission efficiency have also been highlighted [16].

Additional studies have explored a range of influencing factors. The impacts of technological innovation, industrial clustering, and environmental regulations on carbon efficiency have been analyzed [17]. A super-efficiency slack-based model has been utilized to evaluate carbon efficiency across various scenarios [18]. An inverted U-shaped correlation between urbanization and carbon efficiency has been discovered [19]. The roles of renewable energy development and energy intensity in shaping carbon efficiency have also been emphasized [20].

Overall, studies underscore the importance of maximizing economic output while minimizing emissions, the benefits of green energy and innovation, and the influence of urbanization, energy structure, and technology. These insights are critical for developing strategies to enhance carbon efficiency and mitigate climate change.

2.2. Digital Inclusive Finance And carbon Emissions

Digital inclusive finance has become a key driver of sustainable development, with increasing research examining its impact on environmental outcomes, particularly carbon emissions. Studies highlight its potential to mitigate carbon emissions and improve environmental sustainability. Digital inclusive finance has emerged as a crucial driver of sustainable development, with growing attention on its effects on environmental outcomes, particularly carbon emissions. Research underscores its capacity to reduce carbon emissions and enhance environmental sustainability. A negative relationship between digital finance and environmental pollution has been reported, showing its role in lowering pollution emissions [21]. Digital finance has been revealed to be more effective in curbing industrial pollution in heavily polluted regions, helping to reduce regional environmental disparities [22]. It has also been highlighted that digital finance improves marine energy carbon efficiency, with the depth of usage being a key factor [23].

Empirical evidence demonstrates that digital finance significantly reduces industrial pollution emissions in China, emphasizing the importance of digital inclusive finance [24]. The critical role of green technological innovation in reducing carbon emissions has been noted, and digital finance fosters such innovation [25]. The synergy between green finance principles and digital transformation in the banking sector has been underscored, emphasizing the contributions of "green Fintech" and "sustainable digital finance" to promoting environmental sustainability [26].

In conclusion, studies highlight the crucial role of digital inclusive finance in lowering carbon emissions and advancing sustainability. Through fostering green technological innovation, enhancing energy efficiency, and curbing pollution, digital finance supports global efforts in climate change mitigation and sustainable development.

3. Materials and Methods

3.1. Data

China's diverse cities, with varying development levels, provide a valuable foundation for research. The rapid growth of the digital economy and green finance, combined with the uneven development of digital inclusive finance across prefecture-level cities, offers an ideal setting to explore its effect on carbon emission efficiency. This study investigates the impact of digital inclusive finance on urban carbon emission efficiency by analyzing data from 282 Chinese prefecture-level cities between 2011 and 2021. To address significant data gaps in certain years, these periods were excluded, ensuring a robust dataset for the 282 cities included in the analysis.

3.2. Variable Selection

Carbon emission efficiency gauges the amount of carbon emissions generated per unit of economic activity in a region or city, serving as an indicator of resource utilization and environmental protection. This study considers capital, energy, and labor as input factors, while using actual GDP and carbon dioxide emissions as output factors. The super-efficiency SBM model and the CCR model are employed for measurement. Unlike traditional models, the super-efficiency SBM model incorporates undesirable outputs, such as carbon dioxide emissions, and allows for efficiency values greater than 1, providing a more accurate assessment of carbon emission efficiency.

Digital inclusive finance is a financial service model that leverages digital technology to promote inclusivity. It comprises two dimensions: depth and breadth. Depth assesses the popularity and frequency of financial service use, including mobile payments and online lending. Breadth evaluates the geographical reach and diversity of services. This study uses authoritative data from the Digital Finance Research Center at Peking University, derived from big data and surveys, ensuring accuracy and reliability.

3.3. Methodology

3.3.1. Calculation of Carbon Emission Efficiency

The CCR model, a fundamental tool in Data Envelopment Analysis (DEA), measures technical efficiency by assuming uniform technology and production conditions across all units. It evaluates efficiency by calculating scores for each unit and analyzing the contribution of input factors to efficiency. For assessing carbon emission efficiency, the CCR model uses capital, energy, and personnel as inputs, with actual GDP and carbon dioxide emissions as outputs, enabling comparative analysis across cities or regions.

The Super-Efficiency SBM model, also rooted in DEA, accounts for input and output slacks, providing a more precise efficiency assessment. Unlike the CCR model, it allows efficiency scores to exceed 1, offering greater differentiation among efficient units. In carbon emission efficiency evaluations, the model can be applied in input-oriented, output-oriented, or non-oriented modes. For example, the input-oriented mode minimizes inputs while maintaining output, while the output-oriented mode maximizes output for given inputs. This adaptability enables the Super-Efficiency SBM model to deliver more nuanced and comprehensive efficiency evaluations.

3.3.2. Empirical Methodology

This study will utilize panel data from China's prefecture-level cities, sourced from authoritative institutions such as the National Bureau of Statistics, official websites of local governments, and the Institute of Digital Finance at Peking University. The primary variables include carbon emission efficiency (as the dependent variable), digital inclusive finance index (as the core explanatory variable), and other control variables such as urbanization rate, population density, economic aggregation, industrial aggregation, and human capital level.

To conduct the empirical analysis, this study will employ a city- and year-fixed effects model. This model accounts for the heterogeneity among different cities and years, resulting in more accurate and reliable findings. The specific model is formulated as follows:

$$CEE_{it} = \alpha_0 + \alpha_1 DIF_{it} + \beta \sum X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

represent individual fixed effects and year fixed effects, respectively.

Among them, CEE_{it} is the carbon emission efficiency in t year, DIF_{it} is the development of digital inclusive finance in t year, and X_{it} represents a series and control variables. μ_i and λ_t represent individual fixed effects and year fixed effects, respectively.

4. Results

4.1. Descriptive analysis

Table 1: Descriptive statistics

symbol	Obs	Mean	SD	Min	Max
GPD	2402	565.993	1747.12	0	29754
CCR	2402	0.522	0.117	0.176	1.059
SBM	2402	0.327	0.095	0.089	1.024
DIF	2402	184.226	69.209	21.26	359.683
COV	2402	175.794	70.779	4.49	371.79
DEP	2402	179.539	69.232	12.49	354.305
PC	2402	1.514	1.144	0.019	9.84
EC	2402	1.709	3.681	0.018	67.838
IC	2402	1.723	3.579	-0.17	70.848
HCL	2402	171.395	187.775	-89.174	1276.43
UR	2402	0.552	0.142	0.182	1.001

Table 1 outlines the symbols and distributions of variables used in this study's empirical analysis. For the baseline regression, the CCR model is utilized to measure carbon emission efficiency across cities, reflecting performance under existing technological and resource constraints. Significant disparities exist in the development of digital inclusive finance among Chinese cities, with a standard deviation

of 69.209. This variation highlights differences in economic, technological, and cultural factors, as well as geographical imbalances in digital finance development. Digital inclusive finance development comprises two dimensions: coverage breadth and usage depth. Depth reflects the diversity and activity of financial services utilized by users, spanning payments, funds, credit, insurance, investments, and more. It is measured by the total volume of use and user activity, such as per capita transaction frequency and amount. Coverage breadth, enabled by internet connectivity, transcends geographical limits, allowing users to access financial services conveniently, surpassing the physical reach of traditional financial institutions. This ensures efficient and widespread availability of financial services.

4.2. Benchmark regression

Table 2: Benchmark regression

	(1)	(2)	(3)	(4)	(5)	(6)
DIF	0.001** (0.001)	0.001** (0.001)	0.001** (0.001)	0.001** (0.001)	0.001** (0.001)	0.001** (0.001)
UR		-0.186*** (0.061)	-0.181*** (0.061)	-0.183*** (0.062)	-0.180*** (0.062)	-0.189*** (0.061)
PC			-0.020 (0.015)	-0.003 (0.017)	-0.016 (0.017)	-0.012 (0.017)
EC				-0.011*** (0.004)	-0.013*** (0.004)	-0.014*** (0.004)
IC					0.007** (0.003)	0.007** (0.003)
HCL						0.001* (0.001)
Cons	0.295*** (0.032)	0.400*** (0.048)	0.407*** (0.049)	0.403*** (0.049)	0.408*** (0.049)	0.041*** (0.049)
city	YES	YES	YES	YES	YES	YES
year	YES	YES	YES	YES	YES	YES
R-squared	0.284	0.290	0.294	0.295	0.296	0.297
N	2402	2402	2402	2402	2402	2402

Note: ***, **, and * represent significance levels at 1%, 5%, and 10%, respectively. The robustness standard errors are indicated in parentheses next to the regression results.

Table 2 presents the benchmark regression results, with Columns 1 to 6 representing the stepwise regression outcomes. Each column incorporates fixed effects for both city and year. The regression outcomes indicate that, at the 1% significance level, a one-unit increase in the city's digital inclusive finance development level would enhance the city's carbon emission efficiency by 0.001 units. As the development level of digital inclusive finance in cities improves, the accessibility and convenience of financial services are further enhanced, allowing more enterprises and individuals to enjoy quality financial services. With the support of capital, these enterprises and individuals can more actively engage in technological innovation and industrial upgrading, promoting the optimization and upgrading of urban industrial structures. Simultaneously, as digital inclusive finance progresses, the cost of financial services is effectively reduced,

Table 3: Presents the results of the further regression analysis.

	(1)	(2)	(3)	(4)
COV	0.001*** (0.001)	0.001*** (0.001)		
DEP			0.001 (0.001)	0.001 (0.001)
UR		-0.196*** (0.062)		-0.188*** (0.062)
PC		-0.008 (0.017)		-0.012 (0.017)
EC		-0.013*** (0.004)		-0.013*** (0.004)
IC		0.006* (0.003)		0.008** (0.003)
HCL		0.001* (0.001)		0.001** (0.001)
Cons	0.296*** (0.031)	0.413*** (0.048)	0.317*** (0.030)	0.429*** (0.048)
city	YES	YES	YES	YES
year	YES	YES	YES	YES
R-squared	0.286	0.298	0.283	0.295
N	2402	2402	2402	2402

enabling more funds to be allocated towards supporting the technological development of clean and renewable energy, thereby further enhancing carbon emission efficiency.

4.3. Further Regression

Table 3 presents the regression results on the impact of the depth and breadth of digital inclusive finance on urban carbon emission efficiency. As shown in the first and second columns, at the 1% significance level, a one-unit increase in the breadth of digital inclusive finance usage leads to a 0.001-unit improvement in urban carbon emission efficiency. The breadth of digital inclusive finance refers to the coverage and availability of financial services. The internet-based nature of digital finance allows for quick expansion, overcoming geographical constraints and ensuring access even in remote areas, thereby promoting broader service adoption. In contrast, the third and fourth columns show that the depth of digital inclusive finance usage does not significantly improve urban carbon emission efficiency. Depth reflects how frequently and extensively users engage with digital financial services. While deeper usage may offer more comprehensive financial support, it does not necessarily lead to a direct improvement in carbon emission efficiency.

4.4. Mechanism Analysis

Table 4: Mechanism Analysis

	lvsezhuanli1	lvsezhuanli1	lvsezhuanli1
DIF	38.573*** (4.804)		
COV		10.490*** (2.657)	

Table 4: (continued).

DEP			23.218*** (3.460)
Cons	-1604.531*** (184.330)	-617.498*** (126.292)	-1187.730*** (155.736)
city	YES	YES	YES
year	YES	YES	YES
R-squared	0.863	0.851	0.860
N	2402	2402	2402

Table 4 presents the impact of digital inclusive finance development on green technology patents. At the 1% significance level, a one-unit increase in the level of urban digital inclusive finance development results in an additional 38.573 green technology patents. Digital inclusive finance lowers financial barriers for green technology R&D and application by providing funding support for green projects. For example, digital financial services can offer specialized loans, green bonds, and other tailored financing options, enabling more businesses and institutions to invest in green technology development. Green technology directly enhances urban carbon emission efficiency by improving energy utilization, reducing energy consumption, and lowering emissions. For instance, the adoption of clean energy and energy-efficient building technologies helps reduce urban energy use and carbon emissions.

5. Conclusion

Using data from 282 prefecture-level cities, this study examines the impact of digital inclusive finance on urban carbon emission efficiency. The development of digital inclusive finance varies significantly across China's prefecture-level cities, influenced by differences in regional economic development, local digital infrastructure, financial policies, and public acceptance of financial technology. At the prefecture-level, the study confirms that digital inclusive finance positively impacts urban carbon emission efficiency. As digital inclusive finance expands, more businesses and individuals gain access to green financial services, contributing to improved carbon emission efficiency.

Future research could focus on smaller geographic units, such as townships, to better understand the effects of digital inclusive finance on urban carbon emission efficiency. This would provide a more precise assessment of its role in promoting sustainable urban development and offer specific guidance for policy formulation. While obtaining data at the township level may be challenging, leveraging diverse sources such as government statistics, corporate surveys, and satellite lighting data could overcome this obstacle. Additionally, a detailed heterogeneity analysis would be beneficial to account for the significant differences between townships.

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