IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY
EJ EconJournals
ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2026, 16(2), 1038-1047.

EJ EconJournals

The Influence of Inclusive Finance on Atmospheric Carbon Emissions

Simon Osiregbemhe Ilogho, Heinz Eckart Klingelhöfer*

Department of Finance and Investment, Tshwane University of Technology, Pretoria, South Africa. *Email: klingelhoeferhe@tut.ac.za

Received: 16 October 2025 **Accepted:** 25 January 2026 **DOI:** https://doi.org/10.32479/ijeep.22777

ABSTRACT

Global initiatives towards atmospheric carbon emissions reduction have been vested towards a carbon neutral future, but emerging markets, especially in Africa, with emission reduction challenges may capitalise on inclusive financing as a possible influential tool to carbon emission abatement. This study examines the impact of inclusive finance on carbon emissions per capita in 13 South African Development Community (SADC) countries from 2002 to 2022. Financial inclusion was measured using access to Automated Teller Machines (ATMs), bank branches, and personal remittances. A robust Panel Estimated Generalised Least Squares (EGLS) regression was applied through two models, one (a) assessing current-year effects and another (b) using lagged years. Results show that having more ATMs in the previous year reduces carbon emissions per capita in the current year, while having more bank branches in the prior year increases them. This suggests that financial inclusion influences carbon emissions per capita and expanding ATM access may benefit both financial inclusion and environmental sustainability. Moreover, traditional financial inclusion channels, such as bank branches, are associated with higher emissions, while more technologically innovative proxies (ATMs), correspond to reductions. This highlights the importance of promoting innovative, technology-driven-sustainable financial service delivery models.

Keywords: Carbon Emissions, Inclusive Finance, Greenhouse Gas, Southern Africa, Sustainability
JEL Classifications: G21, Q53, Q43, O16

1. INTRODUCTION

1.1. Background

Carbon dioxide (CO_2), an anthropogenic gas, remains a perpetually dominant and preeminent gas contributing to environmental deterioration and degradation worldwide, with profound implications for human well-being, agriculture, societies, and economies (Cheng et al., 2024; Intergovernmental Panel on Climate Change [IPCC], 2022). It is projected that the continued global rise in carbon dioxide emissions is expected to contribute massively to a temperature increase of up to 1.5°C, intensifying global warming (IPCC, 2022; Raihan and Tuspekova, 2022).

In response, several global initiatives have been established to limit carbon emissions, including the United Nations Climate Change Conference of Parties (especially the annual COP, currently COP30 in 2025), regional and national frameworks such as the Paris Climate Agreement and the Energy Bill. Solutions like these align and boost the realisation of broader agendas, as, for example, the Sustainable Development Goals (SDGs) (Hussain et al., 2023). In addition, growing concerns from academics, policymakers, and practitioners have stimulated rigorous scientific research aimed at identifying institutional and socio-economic drivers of activity-related greenhouse gas emissions.

Recently, studies have identified financial inclusion as a potential determinant of greenhouse gas emissions (Dong et al., 2022; Mehmood, 2022). While some studies examined the possible nexus between economic growth and financial inclusion without considering the environmental consequences (Daud et al., 2023;

Emara and El Said, 2021; Siddiki and Bala-Keffi, 2024), other studies have explicitly investigated its ecological impact (Cheikh and Rault, 2024; Ozturk and Ullah, 2022).

Empirical evidence generally suggests that financial inclusion influences carbon emissions, although the findings remain context-dependent (Liu et al., 2022; Shahbaz et al., 2022; Singh et al., 2023). Much of the existing literature, however, neglects the *per capita* dimension of this relationship. Hence, this study seeks to address this gap.

1.2. Problem Statement

Financial inclusion refers to the formal access to financial services and products (Ikeda and Liffiton, 2019; Kling et al., 2020; Omar and Inaba, 2020). Such access facilitates the creation, growth and consolidation of businesses, enhancing domestic productivity within the included population (Siddiki and Bala-Keffi, 2024).

The focus notes of the Consultative Group to Assist the Poor (CGAP, 2017), titled "Vision of the Future: Financial Inclusion 2025," emphasises the pivotal role that financial inclusion plays in stimulating the promotion of sustainable development and economic progress (Cheikh and Rault, 2024; Emara and El Said, 2021). By broadening access to financial services, individuals and businesses are better equipped to facilitate transactions and maintain liquidity, which collectively enhances business performance and national revenue generation. In addition, most of the United Nations' Sustainable Development Goals (SDGs), notably Goals 1, 2, 7, 8, 10, 12, 13, and 15, can be achieved more easily by stimulating financial inclusion (Krannich and Reiser, 2023).

Nonetheless, the expansion of business activities resulting from increased financial inclusion may also intensify physical production and consumption processes, potentially aggravating environmental degradation (Akinsola et al., 2022; Li. et al., 2020; Renzhi and Baek, 2020; Rode et al., 2021). This paradox highlights the intricate relationship between financial inclusion and environmental sustainability.

This problem has led to the need to investigate the impact of financial inclusion on emissions, a topic that has been explored in prior empirical studies. However, several of these works have been reviewed, and the gaps identified are presented in the next section. Therefore, after explaining the research gap, the study outlines its specific objectives and briefly discusses the relevant literature and reviewed theories. After presenting the research methodology, the results and findings are discussed, followed by the policy implications. The study concludes with suggestions for future research.

1.3. Research Gap and Hypothesis

The existing literature (as displayed in the later Table 1) shows that prior studies have examined the relationship between carbon emissions and financial inclusion. However, most of these approaches (to the best of search) have not considered the issue through the lens of carbon emissions per capita. This metric provides a more nuanced understanding of environmental impact by accounting for population size, contextualising emissions at the individual level (per capita). Considering that financial inclusion is inherently measured per individual access to financial services, this perspective is conceptually more consistent in assessing the impact of emissions.

Moreover, even in Africa, prior empirical studies have predominantly focused on other regions, but not specifically on its Southern part. For instance, Adeneye et al. (2023) and Ogede et al. (2024) explored sub-Saharan Africa. Additionally, studies have examined groups of nations with common connections and alliances, such as the Belt and Road Initiative (BRI) and the Organisation for Economic Co-operation and Development (OECD) nations, or the G7 and G20 nations, as seen in works by Asif et al. (2022) and Baskaya et al. (2022), which have focused on the BRICS economies. Despite these contributions, a notable gap remains in the literature, particularly with respect to nations that are part of the Southern African Development Community (SADC). This omission is significant, as these economies may exhibit distinct structural, demographic, and financial characteristics that may influence the financial inclusion and emissions nexus differently.

Addressing this gap in the literature, this paper focuses exclusively on the SADC nations and examines two critical dimensions of financial inclusion: usage and availability. These dimensions are generally considered to be two of the fundamental indicators of an inclusive financial system, providing a comprehensive understanding of the environmental impact of financial inclusion (Le et al., 2020; Renzhi and Baek, 2020).

Accordingly, this study is guided by the following sub-objectives:

1. To examine the effect of the financial inclusion usage dimension on carbon emissions per capita, and
2. To determine the effect of the financial inclusion availability dimension on carbon emissions per capita.

The resulting hypotheses are stated in null form as follows:

- H_{01}: The financial inclusion usage dimension has no significant effect on carbon emissions per capita
- H_{02}: The financial inclusion availability dimension has no significant effect on carbon emissions per capita.

2. LITERATURE REVIEW

In this section, prior empirical studies examining the relationship between carbon emission and financial inclusion are reviewed. Thereafter, the theoretical underpinnings are explained, and the conceptual model employed in this paper is articulated and depicted.

2.1. Inclusive Finance and Carbon Emissions

A growing body of literature has explored the environmental implications of inclusive finance, yet the findings remain inconclusive and, at times, contradictory.

For example, several studies, including Asif et al. (2022), Baskaya et al. (2022), Brahmi et al. (2023), Ding et al. (2022), Dong et al.

Table 1: Empirical studies on financial inclusion and carbon emissions

Authors	Location	Coverages	Estimators	Result
Shahbaz et al. (2022)	China	2011-2017	GLS	Insignificant
Acheampong and Said (2024)	119 countries	2004-2020	D-K	Negative sig.
Hussain et al. (2023)	74 nations	2004-2020	GLS, D-K and P-W	U-shaped
Singh et al. (2023)	24 G7 and G20 nations	2000-2018	OLS, FE and PQR	Negative sig.
Ogede et al. (2024)	sub-Saharan Africa	2000-2018	ARDL and AMG	Positive sig.
Dong et al. (2022)	China	2004-2018	SEM and GSAC	Negative sig.
Zheng and Li (2022)	China	2013-2020	GMM and IV	Negative sig.
Ding et al. (2022)	China	2011-2019	DSDM	Negative sig.
Hussain et al. (2024)	26 Asian nations	2002-2022	PCA	U-shaped
Brahmi et al. (2023)		2013-2023		Negative sig.
Yang et al. (2022)	China	2014-2016	FE	Negative sig.
Le et al. (2020)	31 Asian nations	2004-2014	D-K	Positive sig.
Singh et al. (2023)	India	2009-2018	ARDL	Positive sig.
Khan et al. (2023)	Emerging markets	2011-2021	GMM	Positive sig.
Zhao et al. (2024)	China	2010-2017	PQR	Negative sig.
Baskaya et al. (2022)	BRICS	2002-2019	MMQR	Negative sig.
Asif et al. (2022)	BRICS	1980-2019	ARDL and GC	Negative sig.
Arshad and Parveen (2024)	29 nations	2004-2018	POLS and ARDL	Positive sig.
Hussain et al. (2023)	102 nations	2004-2020	STIRPAT	N-Shaped
Cai and Wei (2023)	BRI countries	2005-2018	CS-ARDL	Positive Sig.
Adeneye et al. (2023)	17 African nations	2004-2021	FE and PQR.	Positive sig.
Mehmood (2022)	India, Pakistan, Bangladesh and Sri-Lanka	1990-2017	CS-ARDL	Positive sig.
Zaidi et al. (2021)	23 OECD nations	2004-2017	CS-ARDL	Positive sig

(Key): GLS (Generalised Least Square), FE (Fixed Effect), OLS (Ordinary Least Square), SEM (Structural Equation Model), PQR (Panel Quantile Regression), AMG (Augmented Mean Group), POLS (Pooled Ordinary Least Square), CS ARDL (Cross-Sectional Augmented Auto Regressive Distributed Lag), STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology), D-K (Driscoll-Kraay standard errors), P-W (Prais-Winsten test), GMM (Generalised Method of Moment), IV (Instrumental Variable regression), MMQR (Method of Moments Quantile Regression), GC (Granger causality), GSAC (Global Spatial Autocorrelation Checks), DSDM (dynamic spatial Durbin model), PCA (Principal Component Analysis), SSA (sub-Saharan Africa), BRI (Belt and Road initiative), VECM (Vector Error Correction Model)

(2022), Yang et al. (2022), Zaidi et al. (2021), and Zheng and Li (2022), document a negative relationship between financial inclusion and carbon emissions. These studies suggest that the expansion of financial services (digitally) can foster improved access to green finance and promote sustainable investment patterns that will contribute to emission reduction.

Conversely, other empirical studies, including Arshad and Parveen (2024), Cai and Wei (2023), Khan et al. (2023), Le et al. (2020) Mehmood (2022), Ogede et al. (2024), Singh et al. (2023) and Zaidi et al. (2021), have reported a positive association: indicating that improved financial inclusion facilitates increased production activities and energy consumption, thus, aggravating the emission of carbon. However, Shahbaz et al. (2022) find no statistically significant relationship, suggesting that the effect may be context-dependent, mediated, or moderated by other structural variables.

Acheampong and Said (2024) explain the interaction (mediation or moderation) between structural variables and financial inclusion, as well as their impact on emissions. They conducted a comparative cross-country analysis, incorporating governance as an interactive variable, and concluded that the heterogeneity in results across countries is mainly attributable to differences in governance quality and levels of economic development—a view in line with the prior position of Ding et al. (2022). Their findings underscore the importance of contextual and institutional dynamics in shaping the nexus between financial inclusion and emissions.

Beyond simple linear associations, several studies reveal nonlinear or conditional relationships. For instance, Hussain et al. (2023), using data from 102 countries between 2004 and 2020, observed an N-shaped relationship: initially positive, turning negative at intermediate stages, and eventually positive again. This pattern suggests that the environmental impact of financial inclusion evolves over time and is influenced by economic development. Similarly, Hussain et al. (2023) and Hussain et al. (2024), analysing 74 global economies and 26 Asian countries respectively, reported an inverted-U relationship in the short run and an upright-U relationship in the long run, further emphasising temporal and developmental conditioning.

Adeneye et al. (2023) also highlighted the role of interaction effects by demonstrating that while fundamental financial inclusion indicators (such as savings, ATM usage, and credit access) tend to increase carbon emissions, sustainable financial inclusion reverses this trend, leading to reduced carbon emissions. Similarly, Singh et al. (2023) reported that the positive impact of financial inclusion on emissions diminishes when moderated by globalisation, suggesting that open economies may experience a more environmentally efficient form of financial deepening.

Collectively, these studies highlight that the relationship between financial inclusion and carbon emissions is complex, non-uniform, and context dependent. A range of factors, including governance quality, economic structure, temporal dynamics, and the sustainability orientation of financial systems, influences it.

The following Table 1 sums up the studies reviewed with their results on financial inclusion and carbon emissions:

2.2. Theoretical Review

This section outlines the theoretical underpinnings that explain the relationship between financial inclusion and carbon emissions. Two major theoretical perspectives are particularly relevant to this study: the Credit Innovation Theory and the Ecological Modernisation Theory (EMT).

The Credit Innovation Theory traditionally establishes the link between financial inclusion, economic growth, and development. It posits that enhanced credit availability and utilisation stimulate innovation, entrepreneurship, and overall societal advancement (Acheampong and Said, 2024; Said, 2024). Access to credit enables individuals and firms to invest in productive ventures and adopt emerging technologies—such as green technologies and environmental innovations that support sustainable development. In this sense, financial inclusion serves as a conduit for environmental improvement, as credit accessibility can facilitate investment in cleaner technologies and green innovations that reduce carbon emissions (Du et al., 2019; Tao et al., 2021; Wang et al., 2023). Thus, the theory provides a conceptual foundation for understanding how financial systems that broaden credit access can indirectly contribute to environmental sustainability (such as emissions reduction).

Complementing this perspective, the Ecological Modernisation Theory (EMT) offers a sociological and policy-oriented explanation for how modern economies address environmental challenges. It argues that environmental degradation can be mitigated through technological innovation, institutional reform, and proactive policy frameworks that integrate ecological considerations into economic decision-making (Julkovski et al., 2021). In this framework, financial inclusion plays a critical role by enabling the flow of financial resources toward green innovation, sustainable production, and environmentally conscious business practices. Accordingly, financial innovativeness (through improved access to financial products and services) can foster a greener economy, enhance environmental governance, and promote sustainability at both micro and macro levels.

However, EMT has been criticised for overlooking the political and ethical dimensions of environmental degradation, focusing instead on structural and technological mechanisms of reform. These limitations, while acknowledged, fall outside the scope of the present study, which concentrates on the financial dimensions of inclusion and their implications for carbon emissions.

2.3. Conceptual Model

Financial inclusion is commonly measured through three dimensions: accessibility (availability), usage, and quality according to the world Bank (World Bank, 2020; World Bank, 2023). While availability and usage can be effectively assessed using secondary data, such as banking infrastructure, account ownership, or transaction records, the quality dimension typically requires primary survey data to capture customer satisfaction, service reliability, and user experience.

Given the reliance of this study on secondary data, the analysis focuses specifically on the availability and usage dimensions of financial inclusion. This approach aligns with prior empirical studies (Chatterjee, 2020; Hussain et al., 2023; Le et al., 2020), which similarly operationalised financial inclusion using measurable, data-driven indicators. The conceptual model (Figure 1), page 6 before research methodology), therefore, posits that improvements in financial inclusion (through greater accessibility and increased usage of financial services) can influence carbon emissions per capita, potentially through both direct economic effects and indirect channels such as technological innovation and efficiency gains. Figure 1 depicts the impact of the proxies of financial inclusion on carbon emission per capita as H_1 and H_2.

3. MATERIALS AND METHODS

3.1. Population and Sample Size

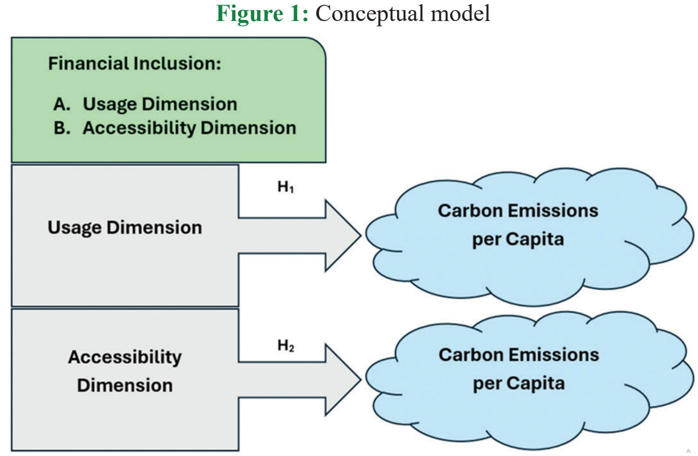
The study examines 13 out of the 16 member countries of the Southern African Development Community (SADC) over the period from 2002 to 2022. The choice of countries and timeframe was informed by data consistency and regional representativeness. Aside from the fact that the major industrial activities (mining and manufacturing) of these 13 countries result in carbon emissions, this choice is motivated as follows:

I. Data limitations: consistent and comparable data for Eswatini were unavailable across the study period
II. Geographical and economic heterogeneity**:** Seychelles and Madagascar possess unique geographic and socio-economic characteristics and are geographically isolated from the mainland economies of the SADC
III. Sectoral composition: Madagascar's predominantly agricultural and low-income structure is more closely associated with methane (CH_4) and nitrous oxide (N_2O) emissions rather than carbon dioxide (CO_2), and
IV. Income disparity: The Seychelles is classified as a high-income, service-based economy with a strong dependence on tourism (World Bank, 2025), making it structurally distinct from most other SADC economies.

3.2. Data Source and Variable Measurement

This study examines the impact of financial inclusion on carbon emissions per capita (CO_2PC) within the SADC region. Financial inclusion is operationalised using two key dimensions (usage and accessibility) consistent with the World Bank's framework and

Figure 1: Conceptual model



Source: Authors

prior studies (Chatterjee, 2020; Le et al., 2020).

- The usage dimension is proxied by personal remittances received (PREMITT_RECIV), reflecting the extent of financial transaction activity among individuals
- The accessibility dimension is captured through two indicators: automated teller machines (ATMs) per 100,000 adults and commercial bank branches (CBANKBRCH) per 100,000 adults, both of which reflect physical access to financial services.

The dependent variable, carbon emissions per capita (CO_2PC), measures the change in per capita CO_2 emissions over time. Three control variables, gross domestic product growth (GDPGR), population growth (POPGR), and greenhouse gas emissions per capita (GHGPC), are incorporated to account for economic, demographic, and environmental influences on carbon emissions. The inclusion of GHGPC as a control variable is particularly justified, as CO_2 constitutes a major component of total greenhouse gas emissions resulting from anthropogenic activities. A non-significant or inverse relationship between CO_2PC and GHGPC would indicate potential model misspecification (Asumadu-Sarkodie and Owusu, 2016; Mansoor and Sultana, 2018).

Data for all variables were obtained from reputable global databases, specifically the World Bank (2024) and Our World in Data (Roser et al., 2023; Ritchie et al., 2023), covering 21 years (2002-2022).

3.3. Measurement of Variables

The measurements of the employed variables were based on the data available, as shown in Table 2.

3.4. Equations

This study's model follows a simple linear specification. For the sake of separation of independent from control variables, the study used two different Greek letters to represent them (β, γ). Financial inclusion measurements (Usage and availability) are represented by their proxies ATMS (Automated Teller Machines availability), CBANKBRCH (commercial bank branch availability) and PREMITT_RECIV (personal remittance received).

$$CO_2PC_{i,t} = \alpha_0 + \beta_1 ATMS_{i,t} + \beta_2 CBANKBRCH_{i,t} + \beta_3 PREMITT\_RECIV_{i,t} + \gamma_1 GDPGR_{i,t} + \gamma_2 POPGR_{i,t} + \gamma_3 GHGPC_{i,t} + \varepsilon_{i,t}$$

With:

- α_0 representing the constant
- β_n revealing the independent variable coefficients,
- γ_n standing for the coefficients of the control variables, and
- $\varepsilon_{i,t}$ being the error term, representing the difference between the statistical value and the observed value, where
- "*i,t*" represent cross-section (*i*) and time (*t*) in the adapted panel data regression model.

The above model represents the effect of the independent and control variables on the dependent variable within the same year.

In addition, the study also examines a year's lagged effect of the independent and control variables, i.e. the effect of the independent and control variables of the prior year on the current year of the dependent variable:

$$CO_2PC_{i,t} = \alpha_0 + \beta_1 ATMS_{i,t-1} + \beta_2 CBANKBRCH_{i,t-1} + \beta_3 PREMITT\_RECIV_{i,t-1} + \gamma_1 GDPGR_{i,t-1} + \gamma_2 POPGR_{i,t-1} + \gamma_3 GHGPC_{i,t-1} + \varepsilon_{i,t-1}$$

The reason for applying this model lies in the fact that data on carbon emissions and financial inclusion are typically captured as a yearly summary at the end of each year. Therefore, the inclusion of the time-lagged model into this study ensures that both estimations together give a more realistic overview of the whole year: the first one is based on the ATMs and commercial bank branches' data at the end of the year; the second one is based on the respective data at the beginning of the year.

3.5. Estimation Technique

The study employed panel regression analysis to estimate the impact of financial inclusion on carbon emissions within the 13 SADC countries. It analysed a series of tests to examine if the model used is appropriate and to diagnose the nature of the dataset:

- The panel unit root test and cross-sectional dependence were essential pre-tests used to determine whether stationarity and cross-sectional dependence were present. The Variance Inflation Factor (VIF) was tested to check for multicollinearity
- At the same time, the Hausman test was used to determine which model was more appropriate: fixed or random effect.

The study estimates its regression analysis using the Panel Estimated Generalised Least Squares Cross-Section Seemingly Unrelated Regression (Panel EGLS) model with fixed effects. The PANEL EGLS was appropriate because it accounts for cross-sectional dependence for a more relevant result.

Table 2: Variables, their measurements and data presentation

Abbreviation	Variables (Type)	Measurement	Data representation (Abbreviation)
FININC	Financial Inclusion (IV)	a. Usage Measure	Personal remittance received (PREMITT_RECIV)
		b. Accessibility Measure	Automated teller machines per 100,000 adults (ATMS), commercial bank branches per 100,000 adults (CBANKBRCH)
CO2PC	CO_2 emissions per capita (DV)	Change in CO_2 emissions per capita (pc) between consecutive years	changes in CO_2 emission pc by country from the preceding to the current previous year
POPGR	Population growth (CV)	Growth (annual %) of country residents within a period	% changes in country population from the preceding year to the current year
GDPGR	Gross Domestic Product growth (CV)	Monetary change (%) in all final productive outputs yearly	% changes in country GDP from the preceding year to the current year

Source: Authors. Key: Independent variable (IV); Dependent variable (DV); Control variable (CV)

4. RESULTS

4.1. Descriptive Statistics

Table 3 presents reasonable mean, maximum, and minimum figures for CO_2 emissions per capita in the examined countries, as well as the number of available ATMs, commercial bank branches, population growth, and personal remittance received and paid. The dataset's highest CO_2 per capita is 9.79 kilo tonnes (kt); its lowest is 0.03 kt CO_2 emission per capita. In addition, the maximum and minimum numbers of ATMs available and commercial bank branches accessible per 100,000 heads in the examined countries of the Southern African Development Community (SADC) region are 74.76 and 0.00, as well as 22.51 and 0.04, respectively. The population growth rate and gross domestic product growth rate (GDPGR) have unexpected minimums of −0.40 and −17.66, respectively, across the 21 years for one of the countries in the SADC. These minimums imply a negative growth rate during that period. The average emission of 1.45 kt CO_2 per capita in the Southern African countries is well below the global average of 4.7 kt per capita as of 2023 (International Energy Agency [IEA], 2023). The mean value for the ATMs available per 100,000 adults (16.69) is also low compared to the global average of 39 per 100,000 adults, according to the International Air Transport Association (IATA, 2023). This value can be explained by the level of development in Africa. The average global GDP growth rate is 3% (World Bank, 2024), whereas it is 3.89% for the 13 Southern African countries examined.

In addition, the standard deviation of available ATMs reveals variation among these countries: while the maximum number is 74.76 ATMs per 100,000 adults in one country, other countries, however, have a very low number of available ATMs, with some as low as zero per 100,000 adults. Likewise, as shown in the standard deviation figure for CBANKBRCH, there are variations in the available commercial bank branch figures for the examined countries when compared individually, as shown in the standard deviation figure for CBANKBRCH.

4.2. Pre-Examinations

Table 4 for the stationary test presents the outcome of the unit root test at the level and first difference.

- At the level, GDPGR is stationary in all the employed unit root test measures such as LLC, IPS, ADF and PP. POPGR is stationary, based on the results of at least three of the four methods at the level. Unfortunately, the rest of the variables is not stationary, as indicated by the results of every method employed, necessitating a further examination of first differences.
- The first difference examination shows that all the remaining variables are stationary at a level under every method. Since only ATMS, CBANKBRCH, PREMITT_RECIV, CO2PC, and GHGPC need to be tested for first differences, these first-difference representations are used in the analysis.

4.3. Regression Results

After examining the unit root test, the study conducted a regression test against the hypotheses using the least squares regression method. The least squares regression usually requires checking whether the fixed or the random effect is more appropriate.

The Hausman test was conducted to determine which one of the two methods is more suitable for the panel data examined between the two models (Table 5). Usually, when the panel data has more time rather than more cross-sections, the fixed effect tends to be more appropriate, and this is confirmed by the statistically significant level (0.0095) of the Hausman test: The hypothesis of random effect should be rejected as inconsistent when the Chi-square probability value is below 0.05, but it may be accepted otherwise. In this case, the Chi-square P-value is clearly below 0.05 for all the tested hypotheses, indicating a preference for the fixed effect (Table 5).

With the P-values for both the models without lag (1.00 and 0.43) as well as with lag (1.00 and 0.71) in Table 6, the cross-section dependence test from the Panel EGLS (Cross-section SUR) leads

Table 3: Descriptives

Obs: 273	CO2PC	ATMS	CBANKBRCH	GDPGR	GHGPC	POPGR	PREMITTRECIV
Mean	1.45	16.69	6.01	3.89	4.89	2.11	3.36E+08
Max	9.79	74.76	22.51	21.45	13.08	3.75	3.26E+09
Min	0.03	0.00	0.04	−17.66	0.95	−0.40	0.00
Standard deviation	2.20	19.48	5.25	4.68	3.10	1.05	5.32E+08

Source: Authors' computation

Table 4: Panel unit root test

Test	Results @Level				Results @First difference			
Methods	LLC	IPS	ADF	PP	LLC	IPS	ADF	PP
ATMs	0.000	0.254	0.310	0.663	0.195	0.009	0.023	0.000
CBANKBRCH	0.272	0.848	0.949	0.926	0.000	0.000	0.000	0.000
PREMITT_RECIV	0.851	0.953	0.616	0.226	0.000	0.000	0.000	0.000
POPGR	0.023	0.032	0.035	0.922	N/A	N/A	N/A	N/A
GDPGR	0.000	0.000	0.000	0.000	N/A	N/A	N/A	N/A
GHGPC	0.652	0.963	0.838	0.091	0.000	0.000	0.000	0.000
CO2PC	0.833	0.957	0.783	0.783	0.000	0.000	0.000	0.000

Key: Im, Pesaran and Shin W-stat (IPS), Levin, Lin and Chu t* (LLC), Augmented Dickey-Fuller Chi-square (ADF), Phillips-Perron-Chi-square (PP). Source: authors to acceptance of the null hypothesis "No cross-section dependence in weighted" for both methods. Additionally, Table 6 indicates that the centred VIF results for multicollinearity are below 5 (even under the sometimes used very strict cut-off rate of 2), suggesting that there is no serious multicollinearity.

In addition, Table 6 displays the results of the Panel EGLS (cross-section SUR) for the two models: the one with "no lag" and the one with "lagged IV" (independent variables IV).

In the result for the first model with no lag, all variables had statistically significant p-values, except CBANKBRCH (0.13) and PREMITT_RECIV (0.42). Moreover, ATMS, GHGPC and GDPGR showed positive coefficients, while POPGR's coefficient was negative. The Durbin-Watson statistic (2.28) is within the acceptable range, indicating no autocorrelation and showing that the model is a good fit for this examination. The R-squared (0.51) further reveals that the independent and control variables explain 51% of the variation in the dependent variable.

Not much different were the results for the second analysis with lagged IV in Table 6, as introduced in the model specification, which showed that all explanatory variables had statistically significant P-values (within the 0.1 threshold). However, in comparison to the previous analysis, the coefficients of ATMS (−0.0063) and CBANKBRCH (0.0055) switch their direction, while PREMITT_RECIV has a statistically significant coefficient of 0.0000.

Again, the Durbin-Watson statistic (2.12) is within the expected range, indicating no autocorrelation. The R-squared (0.42) shows that the independent and control variables explain 42% variation in the dependent variable. Thus, the model is a good fit for this examination.

Table 5: Hausman test

Test summary	Chi-square statistic	Chi-square d.f.	Prob.
Cross-section random	18.597195	7	0.0095

Source: authors

4.4. Interpretation and Discussion

The interpretation of these results is as follows:

- (Only) changes in ATM accessibility in the current year, as a financial inclusion proxy, have a statistically significant positive impact on CO_2 emissions pc in the same year in Southern Africa; meaning an increase in ATMs by 1 per 100,000 adults will lead to a 0.0066 kt (which is 6.6 tonnes) rise in CO_2 emissions pc within the same year.
- Changes in CBANKBRCH and PREMITT_RECIV showed either a not statistically significant impact or none at all, respectively, for the current year.
- Changes in GDPGR have statistically significant positive impacts on CO_2 emissions pc. This means that a 1% increase in GDP growth in Southern Africa would lead to higher CO_2 emissions by 0.0095 kt (9.5 tonnes per capita) within the same year in that region.
- Similarly, a percentage increase in population growth (POPGR) in Southern Africa appears to result in a statistically significant reduction in CO_2 emissions by 0.035 kt (35.5 tonnes per capita) in the same year.

These results for the first model (the one without lag) suggest that only one of the accessibility dimension proxies (ATM accessibility per 100,000 adults) influences CO_2 emissions. In contrast, the usage dimension has no impact. In addition, the result for changes in the greenhouse gas emission pc (GHGPC) shows the expected positive impact on CO2PC (otherwise it would be an anomaly, indicating a poor model). Based on these outcomes, the null hypothesis "Financial inclusion does not impact the CO_2 emissions pc in Southern Africa" cannot be rejected for the commercial bank branches and personal remittance received proxies but is rejected for the ATM accessibility proxy.

The second analysis with lagged IV in Table 6, as introduced in the model specification, showed that all explanatory variables had statistically significant p-values (within the 0.1 threshold). However, in comparison to the previous analysis, the coefficients of ATMS (−0.0063) and CBANKBRCH (0.0055) switch their direction. Hence, the increase in ATMS in the end of the previous year resulted in a decrease in CO_2 emissions per capita in the

Table 6: Panel least squares regression

CO_2PC									
IV	No Lag		Imp.	Lag. IV		Imp.	Dec.	No Lag	Lag. IV
	Coefficient	P-value		Coefficient	P-value			CVIF	CVIF
ATMS	0.0066	0.01	Pos.	-0.0063	0.00	Neg.	Rej.	1.15	1.02
CBANKBRCH	−0.0052	0.13	Neglig.	0.0055	0.00	Pos.	Rej.	1.64	1.03
PREMITT_RECIV	0.0000	0.42	Neglig.	0.0000	0.02	Neglig.	Cannot be rej.	1.52	1.05
POPGR	−0.0355	0.01	Neg.	−0.0106	0.03	Neg.		1.42	1.17
GHGPC	0.0471	0.00	Pos.	0.0147	0.00	Pos.		1.14	1.08
GDPGR	0.0095	0.00	Pos.	0.0006	0.10	Pos.		1.40	1.19
R-Sqd.	0.51			0.42					
D-W stat	2.28			2.12					

	CSD: Breusch-Pagan LM		Pesaran CD	
	Stat.	Prob.	Stat.	Prob.
Without Lag	33.70	1.00	−0.77	0.43
With Lag	10.81	1.00	−0.36	0.71

Key: IV (independent variable), P-v (probability value), CVIF (centered variance inflation factor), D-W stat (durbin watson statistic), R-Sqd (R-squared), Neglig. (negligible), Pos. (positive), Rej. (rejected), Neg. (negative), Lag. (lagged), Dec. (decision), Imp. (impact), CSD (cross-section dependence). Source: Authors current year (by 0.0063 kt). The addition of more commercial bank branches at the end of the previous year would increase emissions by 0.0055 kt. At the same time, changes in the usage dimension of financial inclusion (PREMITT_RECIV), with a statistically significant coefficient of 0.0000, still does not have any impact.

The results for the control variables were similar to those from the first examination, indicating no difference between these independent variables when lagged or not. These results imply that the increased POPGR and GDPGR for a year, respectively, have a negative and positive impact on the subsequent year's CO_2 emissions.

The outcomes for the second model provide a second perspective on reality, as previous year inclusion always influences the start of the present year's emissions. Therefore, based on these outcomes, the null hypothesis "Financial inclusion does not impact the CO_2 emissions pc in Southern Africa" is rejected entirely for the accessibility dimension, indicating that it has an impact on CO_2 emissions pc. In contrast, the influence of the usage dimension (personal remittance) remains negligible.

4.5. Theoretical Findings

There is no disparity between the results obtained and the expected outcomes based on the Credit Innovation theory. The Credit Innovation theory indicates that a credit innovation (a financial innovation) that improves credit availability, access, and usage (financial inclusion) facilitates increased business activities and operations, which impact the environment. Consequently, it is expected that credit innovation will indirectly impact carbon emissions positively or negatively; however, the findings indicate a mixed outcome, in agreement with the theory. The usage dimension (personal remittance) does not appear to impact carbon emissions per capita, while ATMs and commercial bank branches may indeed have an influence. These findings align entirely with the theoretical expectations of this paper, which suggest that credit innovation indirectly impacts the environment through increased access to financial services, leading to more business activities.

In addition, the Ecological Modernisation Theory (EMT) suggests that technological innovation, institutional reform and economic growth in societies can reduce human impact on the environment. Therefore, financial innovations that lead to efficient and high-quality financial services are expected to mitigate the impact of society on the environment. In this case, the results showed that financial inclusion does impact carbon emissions. In both models, at least one of the accessibility proxies leads to increases, and (in the lagged variant), more ATMs result in a reduction in carbon emissions per capita, indicating that the findings partially align with EMT.

5. CONCLUSIONS AND RECOMMENDATIONS

We examined the impact of inclusive finance on per capita carbon emissions using the usage and accessibility measures as measurements. The usage and accessibility measures were proxied employing personal remittance received, as well as ATMS and commercial bank accessibility. To this end, the study used the PANEL EGLS cross-section SUR for data covering the period from 2002 to 2022 for thirteen SADC nations. The findings suggest that increased ATM availability at the start of the year (resulting from an increase in the previous year) reduces carbon emissions per capita for the current year. In contrast, the increased presence of commercial banks may lead to higher carbon emissions.

Based on the findings, existing ATMs at the beginning of the year may not only be beneficial from a financial inclusion point of view, but also from an environmental perspective, because they may reduce emissions in the current year. Hence, while adding ATMs in a year may increase emissions within this year, it lessens emissions later. Therefore, management may consider maintaining the number of existing ATM facilities rather than removing them, even when economies become increasingly digitalised.

In addition, it is also important to note that the financial inclusion proxies used in this study are still quite traditional, which may explain the outcome of the results. The more traditional financial inclusion infrastructure (commercial bank branch) leads to higher carbon emissions per capita, while the less conventional facility (ATMs) reduces them. This finding may suggest that more progressive and innovative financial inclusion service facilities could help achieve lower carbon emissions per capita in the SADC. Therefore, it may make sense to encourage financial institutions' management to invest in research and development towards more innovative financial inclusion facilities.

Alternatively, suppose the development towards innovative financial inclusion yields a greater cost than benefit. In that case, it may be a good idea to encourage partnerships between traditional banks and Fintech companies to realise synergies. Such partnerships, with their financial innovations and digitalisation, could increase informal community penetration.

Finally, one needs to consider that in many sub-Saharan countries, the focus has probably been more on providing basic financial services physically than on incorporating the advantages of mobile financial services into financial service provision. Hence, the traditional financial inclusion proxies used in this study limit the managerial and policy considerations (of the findings) to traditional, i.e. physically stationed financial inclusion structures (like ATMs and bank branches).

This study was limited in its scope to examining the broad category of inclusive financing, focusing more on traditional mediums like commercial banks and ATMs. Therefore, future studies could change the focus to digitalised financial inclusion. In addition, rather than the mean regression assessment used in this paper, future studies could examine the detailed impact of inclusive financing at different emission levels using quantile regression.

REFERENCES

Acheampong, A.O., Said, R. (2024), Financial inclusion and the global net-zero emissions agenda: Does governance quality matter? Energy Economics 137, 107785.

Adeneye, Y., Rasheed, S., Ooi, S.K. (2023), Does financial inclusion spur CO_2 emissions? The marginal effects of financial sustainability. IIMBG Journal of Sustainable Business and Innovation, 1(2), 77-97.

Akinsola, G.O., Ojetunde, S.B., Bello, M.A., Ayinde, O.E., Durotoye, O.E. (2022), Mobile financial services and rural household livelihoods: Evidence from Kwara State, Nigeria. Journal of Agriculture and Human Ecology, 6(1), 1-9.

Arshad, A., Parveen, S. (2023), Exploring the impact of financial inclusion on greenhouse gas emissions (CO_2) and energy efficiency: Evidence from developing countries. Environment, Development and Sustainability, 26, 27723-27738.

Asif, S., Zafar, A., Zahoor, U., Shahbaz, M., Shahzad, A. (2022), Examining the impact of financial inclusion on CO_2 emission in BRICS: Evidence from panel data analysis. Res Militaris, 12(6), 2623-2636.

Asumadu-Sarkodie, S., Owusu, P.A. (2017), Recent evidence of the relationship between carbon dioxide emissions, energy use, GDP, and population in Ghana: A linear regression approach. Energy Sources, Part B: Economics, Planning, and Policy, 12(6), 495-503.

Baskaya, M.M., Samour, A., Tursoy, T. (2022), The financial inclusion, renewable energy and CO_2 emissions nexus in the BRICS nations: New evidence based on the method of moments quantile regression. Applied Ecology and Environmental Research, 20(3), 25772595.

Brahmi, M., Esposito, L., Parziale, A., Dhayal, K.S., Agrawal, S., Giri, A.K., Loan, N.T. (2023), The role of greener innovations in promoting financial inclusion to achieve carbon neutrality: An integrative review. Economies, 11(7), 194.

Cai, X., Wei, C. (2023), Does financial inclusion and renewable energy impede environmental quality: Empirical evidence from BRI countries. Renewable Energy, 209, 481-490.

Chatterjee, A. (2020), Financial inclusion, information and communication technology diffusion, and economic growth: A panel data analysis. Information Technology for Development, 26(3), 607-635.

Cheikh, N.B., Rault, C. (2024), Financial inclusion and threshold effects in carbon emissions. Energy Policy, 192, 114265.

Cheng, Q., Zhao, X., Zhong, S., Xing, Y. (2024), Digital financial inclusion, resident consumption, and urban carbon emissions in China: A transaction cost perspective. Economic Analysis and Policy, 81, 1336-1352.

Consultative Group to Assist the Poor (CGAP). (2017), Vision of the Future: Financial Inclusion 2025 (Focus Note, CGAP. Available from: https://www.cgap.org/sites/default/files/focus-note-vision-of-the-future-jun-2017_0.pdf

Daud, S.N.M. (2023), Financial inclusion, economic growth and the role of digital technology. Finance Research Letters, 53, 103602.

Ding, X., Gao, L., Wang, G., Nie, Y. (2022), Can the development of digital financial inclusion curb carbon emissions? Empirical test from spatial perspective. Frontiers in Environmental Science, 10, 1045878.

Dong, J., Dou, Y., Jiang, Q., Zhao, J. (2022), Can financial inclusion facilitate carbon neutrality in China? The role of energy efficiency. Energy, 251, 123922.

Du, K., Li, P., Yan, Z. (2019), Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data. Technological Forecasting and Social Change, 146, 297-303.

Emara, N., El Said, A. (2021), Financial inclusion and economic growth: The role of governance in selected MENA countries. International Review of Economics and Finance, 75, 34-54.

Hussain, S., Ahmad, T., Ullah, S., Rehman, A.U., Shahzad, S.J.H. (2024), Financial inclusion and carbon emissions in Asia: Implications for environmental sustainability. Economic and Political Studies, 12(1), 88-104.

Hussain, S., Akbar, M., Gul, R., Shahzad, S.J.H., Naifar, N. (2023), Relationship between financial inclusion and carbon emissions: International evidence. Heliyon, 9(6), e16472.

Hussain, S., Gul, R., Ullah, S., Waheed, A., Naeem, M. (2023), Empirical nexus between financial inclusion and carbon emissions: Evidence from heterogeneous financial economies and regions. Heliyon, 9(3), e13164.

Ikeda, J., Liffiton, K. (2019), Fintech for the Water Sector: Advancing Financial Inclusion for more Equitable Access to Water. World Bank. Available from: https://hdl.handle.net/10986/31417

Intergovernmental Panel on Climate Change. (2022), Climate Change 2022: Impacts, Adaptation and Vulnerability - Working Group II contribution to the Sixth Assessment Report. Available from: https://www.ipcc.ch/report/ar6/wg2

International Air Transport Association. (2023), Global Outlook for Air Transport: Highly Resilient, Less Robust [Report]. Available from: https://www.iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport----june-2023

International Energy Agency. (2023), The World's Top 1% of Emitters Produce Over 1 000 Times More CO_2 than the Bottom 1% [Commentary]. Available from: https://www.iea.org/commentaries/the-worlds-top-1-of-emitters-produce-over-1000-times-more-co2-than-the-bottom-1

Julkovski, D.J., Sehnem, S., Bennet, D., Leseure, M. (2021), Ecological modernisation theory (EMT): Antecedents and successors. Indonesian Journal of Sustainability Accounting and Management, 5(2), 324-338.

Khan, K., Luo, T., Ullah, S., Rasheed, H.M.W., Li, P.H. (2023), Does digital financial inclusion affect CO_2 emissions? Evidence from 76 emerging markets and developing economies (EMDE's). Journal of Cleaner Production, 420, 138313.

Kling, G., Pesqué-Cela, V., Tian, L., Luo, D. (2022), A theory of financial inclusion and income inequality. The European Journal of Finance, 28(1), 137-157.

Krannich, A.L., Reiser, D. (2023), United Nations Sustainable Development Goals 2030, The. In: Encyclopedia of Sustainable Management. Switzerland: Springer International Publishing. 3862-386.

Le, T.H., Le, H.C., Taghizadeh-Hesary, F. (2020), Does financial inclusion impact CO_2 emissions? Evidence from Asia. Finance Research Letters, 34, 101451.

Li, L., Li, Q., Huang, L., Wang, Q., Zhu, A., Xu, J., & Chan, A. (2020), Air quality changes during the COVID-19 lockdown over the Yangtze River Delta Region: An insight into the impact of human activity pattern changes on air pollution variation. Science of the Total Environment, 732, 139282.

Liu, D., Xie, Y., Hafeez, M., Usman, A. (2022), The trade-off between economic performance and environmental quality: Does financial inclusion matter for emerging Asian economies? Environmental Science and Pollution Research, 29, 29746-29755.

Mansoor, A., Sultana, B. (2018), Impact of population, GDP and energy consumption on carbon emissions: Evidence from Pakistan using an analytic tool IPAT. Asian Journal of Economics and Empirical Research, 5(2), 183-190.

Mehmood, U. (2022), Examining the role of financial inclusion towards CO_2 emissions: Presenting the role of renewable energy and globalisation in the context of EKC. Environmental Science and Pollution Research, 29(11), 15946-15954.

Ogede, J.S., Oduola, M.O., Tiamiyu, H.O. (2024), Income inequality and carbon dioxide (CO_2) in sub-Saharan Africa countries: The moderating role of financial inclusion and institutional quality. Environment, Development and Sustainability, 26(7), 18385-18409.

Omar, M.A., Inaba, K. (2020), Does financial inclusion reduce poverty and income inequality in developing countries? A panel data analysis. Journal of Economic Structures, 9(1), 37.

Ozturk, I., Ullah, S. (2022), Does digital financial inclusion matter for economic growth and environmental sustainability in OBRI economies? An empirical analysis. Resources, Conservation and Recycling, 185, 106489.

Raihan, A., Tuspekova, A. (2022), The nexus between economic growth, renewable energy use, agricultural land expansion, and carbon emissions: New insights from Peru. Energy Nexus, 6, 100067.

Renzhi, N., Baek, Y.J. (2020), Can financial inclusion be an effective mitigation measure? Evidence from panel data analysis of the environmental Kuznets curve. Finance Research Letters, 37, 101725.

Ritchie, J., Rodés-Guirao, L., Mathieu, E., Gerber, M., Ortiz-Ospina, E., Hasell, J., Roser, M. (2023), Population Growth. Our World in Data. Available from: https://ourworldindata.org/population-growth

Rode, A., Carleton, T., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., & Yuan, J. (2021), Estimating a social cost of carbon for global energy consumption. Nature, 598(7880), 308-314.

Roser, M., Rohenkohl, B., Arriagada, P., Hasell, J., Ritchie, J., Ortiz-Ospina, E. (2023), Economic Growth. Our World in Data. Available from: https://ourworldindata.org/economic-growth

Said, R. (2024), Financial inclusion and environmental pollution in sub-Saharan Africa: Moderating effects of economic growth and renewable energy. Environmental Science and Pollution Research, 31(43), 55346-55360.

Shahbaz, M., Li, J., Dong, X., Dong, K. (2022), How financial inclusion affects the collaborative reduction of pollutant and carbon emissions: The case of China. Energy Economics, 107, 105847.

Siddiki, J., Bala-Keffi, L.R. (2024), Revisiting the relation between financial inclusion and economic growth: A global analysis using panel threshold regression. Economic Modelling, 135, 106707.

Singh, A.B., Tandon, P., Jasuja, D. (2023), Does financial inclusion spur carbon emissions in India: An ARDL approach. Management of Environmental Quality: An International Journal, 34(2), 511-534.

Singh, A.K., Raza, S.A., Nakonieczny, J., Shahzad, U. (2023), Role of financial inclusion, green innovation, and energy efficiency for environmental performance? Evidence from developed and emerging economies in the lens of sustainable development. Structural Change and Economic Dynamics, 64, 213-224.

Tao, R., Su, C.W., Naqvi, B., Rizvi, S.K.A. (2022), Can Fintech development pave the way for a transition towards low-carbon economy: A global perspective. Technological Forecasting and Social Change, 174, 121278.

Wang, Y., Wang, X., Ning, M., He, J., He, J., Lei, Y., Hou, S. (2023), The collaborative pollutants and carbon dioxide emission reduction and cost of ultra-low pollutant emission retrofit in China's cement kiln. Journal of Cleaner Production, 405, 136939.

World Bank, European Investment Bank. (2020), City Climate Finance Gap Fund [Web Page]. Available from: https://www.worldbank.org/en/programs/gap-fund

World Bank. (2023) Global Urban Carbon Emissions: Data Sources [Technical Report]. Available from: https://www.citygapfund.org/wp-content/uploads/2024/09/p1747640cd669703f0a79104b9b4b9e0ad0.pdf

World Bank. (2024), GDP Per Capita (Current US$) - Sub-Saharan Africa. Available from: https://data.worldbank.org/indicator/ny.gdp.pcap.cd?end=2024&locations=zg&most_recent_year_desc=false&start=2024&type=points&view=map&year=2022

World Bank. (2025), World Bank Income Groups [Dataset]. Major Processing by Our World in Data. World Bank, "Income Classifications" [Original Data]. Available from: https://archive.ourworldindata.org/20251021-211801/grapher/world-bank-income-groups.html [Last accessed on 2025 Oct 24].

Yang, Z., Yu, L., Liu, Y., Yin, Z., Xiao, Z. (2022), Financial inclusion and carbon reduction: Evidence from Chinese counties. Frontiers in Environmental Science, 9, 793221.

Zaidi, S.A.H., Hussain, M., Zaman, Q.U. (2021), Dynamic linkages between financial inclusion and carbon emissions: Evidence from selected OECD countries. Resources, Environment and Sustainability, 4, 100022.

Zhao, C., Taghizadeh-Hesary, F., Dong, K., Dong, X. (2024), Breaking carbon lock-in: The role of green financial inclusion for China. Journal of Environmental Planning and Management, 67(3), 564-593.

Zheng, H., Li, X. (2022), The impact of digital financial inclusion on carbon dioxide emissions: Empirical evidence from Chinese provinces data. Energy Reports, 8, 9431-9440.