Inzinerine Ekonomika-Engineering Economics, 2025, 36(4), 498–515

Does Greenwashing Hinder the Contribution of Fintech to Environmental Sustainability? Evidence from BRICS Countries

Oktay Ozkan[1], Magdalena Radulescu[2,3,4]*, Mehmet Akif Destek[4,5,6], Madalina Brutu[2]

[1]*Department of Business Administration, Faculty of Economics and Administrative Sciences, Tokat Gaziosmanpasa University, Tokat, Turkey*
ARUCAD Research Centre, Arkin University of Creative Arts and Design, Northern Cyprus
Mersin 10, Turkey
E-mail. oktay.ozkan@gop.edu.tr

[2]*Department of Finance, Accounting and Economics, National University of Science and Technology Politehnica Bucharest, Pitesti University Center, Pitesti, Romania,*
[3]*BEU-Scientific Research Center, Baku Engineering University, Baku, Azerbaijan*
[4]*Research Methods Application Center of UNEC, Azerbaijan State University of Economics (UNEC), Baku AZ1001, Azerbaijan*
[5]*Department of Economics, Gaziantep University, Gaziantep, Turkey*
[6]*Economic Research Center (BAAU-ERC), Baku Eurasian University, Baku, Azerbaijan*
*E-mail. *magdalena.radulescu@upit.ro (corresponding author); adestek@gantep.edu.tr; madalina.brutu@upit.ro*

https://doi.org/10.5755/j01.ee.36.4.40054

The greenwashing problem arises when companies provide misleading information about environmental sensitivity or exaggerate the sensitivity in question. At this point, it is claimed that financial technologies are seen as a solution to greenwashing. However, it is not known how environmentally friendly fintech companies are, in other words, whether fintech activities are a greenwashing problem. In this regard, this study investigates the effects of fintech on the novel load capacity factor to examine whether fintech creates a greenwashing problem for BRICS countries. In doing this, the period of 1992-2021 is analyzed with the quantile-on-quantile technique. According to empirical findings, financial technology activities harm environmental quality. Therefore, it is concluded that companies carrying out fintech activities for BRICS countries cause the greenwashing so the problem of greenwashing hinders fintech's potential contributions to the environment. Based on the findings, policy recommendations are made to audit companies conducting R&D studies on fintech and to penalize companies that make fake reports.

Keywords: *FinTech; Load Capacity Factor; Greenwashing; Quantile-on-Quantile Regression; BRICS*.

Introduction

The 21st century can be considered as the period in human history when efforts to reduce problems such as global warming and climate change, which emerged as a result of the destruction caused to the environment, especially in the last 100 years (since the industrial revolution), came to the fore. Efforts to return to a low-emission production structure such as renewable and nuclear energy from the periods when industrialization, especially economic activities, were entirely based on fossil fuels, are dominant at the international level. Parallel to this situation, interest in environmental economics literature has been increasing in academic research in recent years. Researchers primarily focus on studies to identify factors that increase environmental degradation and identify the negative environmental effects of factors such as economic growth, industrialization, and urbanization. Recently, they have been focusing on policy recommendations aimed at reducing the environmental damage of factors that increase environmental degradation, especially economic growth, in other words, to achieve green growth targets.

The concept of "green growth", which is simply defined as a type of growth in which production and demand-based emissions are controlled through green technological innovations to support access to green production and supply chains (Chen *et al.*, 2023), is not the same difficulty for every country in reaching the targets. Developed countries can bear the costs of practices such as energy transition, energy technology and waste management, which initially involve high costs and harm economic activities. On the other hand, it is known that developing countries, which made their economic breakthroughs relatively late, experience funding difficulties in keeping up with this transformation and need technologies and financial support that can be transferred from developed countries. As a matter of fact, many international meetings are held to protect environmental quality and reduce the effects of climate change. Finally, when we look at the COP28 decisions held in Dubai, we see that they are trying to overcome the difficulties of developing countries in complying with their commitments in the context of sustainability. Namely, the most important decisions taken at the meeting were "accelerating a fair, orderly and equitable energy transition" and "fixing climate finance". Moreover, the idea of "establishing a loss and damage fund for the most vulnerable countries", which was decided in the first days of the meeting, indicates that countries with fund shortages are having problems with the green transformation (UNFCCC, 2023).

While providing funding support to countries experiencing funding shortages for green transformation

through intergovernmental agreements is an important transfer mechanism, the fact that international investors invest in companies operating in the field of green transformation also reveals the importance of green finance as a whole. Similarly, developing countries benefiting from the green technology know-how of developed countries is another important element that contributes to the global ecosystem. On the other hand, a claim that green finance or green technologies may fail and even cause further harm to the environment has begun to be discussed in recent years. This misleading practice of companies that claim to be environmentally friendly but are not, or show their environmental sensitivity as more exaggerated than it is, brings the concept of greenwashing to the fore (Nygaard & Silkoset, 2023). Greenwashing enables businesses to convey misleading information about the ecological benefits of their products and practices by making false claims, using ambiguous language, or providing incomplete information (Self *et al.*, 2010; Lee *et al.*, 2018; Das *et al.*, 2023). Due to greenwashing, investors support companies they consider environmentally friendly in financial markets, or consumers choose the products of these companies. This could reverse the possible environmentally beneficial effects of green finance. Offering a solution to this problem, Xie et al. (2023) claims that financial technologies (fintech) can offer a solution against greenwashing.

The development of financial technologies can have various effects on the environment. Fintech refers to innovative technology used in financial services through technologies such as the internet, mobile internet, big data and artificial intelligence, which can create significant changes in the way financial transactions are carried out. Types of fintech include peer-to-peer lending, crowdfunding, big data credit assessment, robo-advisors, blockchain and virtual currencies (Udeagha & Ngepah, 2023). It is known that there are conflicting views regarding the effects of fintech on the environment, and this conflict of opinion also exists regarding the effects of technological innovations on the environment in general. According to optimistic views, fintech innovation can contribute to environmental quality by leading to direct effects such as reducing paper waste, digitalization, reducing banking visits and saving transportation fuel consumption (Qin *et al.* 2024). On the other hand, there are also claims about the possible direct harm of fintech innovations to the environment. For example, some fintech solutions use blockchain technology and it is known that this technology requires heavy electricity consumption (Goodkind *et al.* 2020). Similarly, large data processing requirements can also lead to significant energy consumption. In addition, the constant renewal of devices required to maintain fintech services can also raise the problem of waste. In summary, if fintech companies, which are seen as a solution to the possible greenwashing obstacle of green finance and green technologies, benefit from fossil energy resources in fintech services or do not manage the waste conversion process correctly, fintech companies themselves may emerge as greenwashing.

In light of the above discussions, the aim of this study is to investigate whether greenwashing is valid in the fintech-environment relationship for BRICS countries by investigating the effects of financial technologies on environmental quality. In doing so, the novel load capacity factor, which considers both the supply and demand sides of environmental quality, is considered as an indicator of environmental quality, instead of only addressing the demand side of the environment. The reason why BRICS countries are chosen as a sample is that we assume that the fintech-environment relationship will be determined more clearly for countries that receive international financial aid and have a relatively more developed financial sector among developing countries, rather than developed countries that do not experience funding shortages. In addition, BRICS are economies with a robust growth rate and they are among high pollutant economies of the world (Wei *et al.*, 2024). China, Brazil, and India have industrialized economies where manufacturing industries prevail, while Russia and South Africa are more like natural resources-based economies where resources extraction industries are heavily pollutant (Shao *et al.*, 2019).

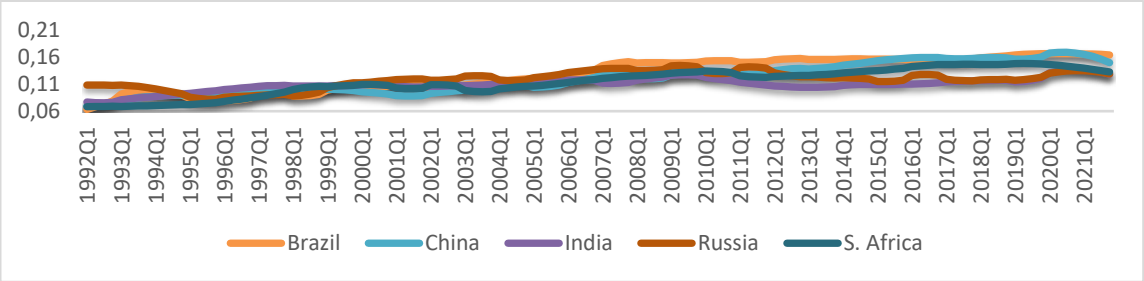


Figure 1. Financial Technology in BRICS Countries

Fintech adoption rates in the BRICS countries range between 82–87 % comparing to an average global adaptation rate of 64 %. China, India, Russia and South Africa are on the first 4 positions in the world considering their fintech adoption rates. Brazil displays a lower adoption rate of 64 %, same as average world level (EY Report, 2021). This high adoption rate is explained by rapid growth rates experienced by BRICS nations (together they account for 25 % of global GDP) and rising income and spending determined a significant increase of the demand for financial products and services. Still, large part of the population in BRICS countries remains unbanked (25–33 %) (Global Finance, 2021), but the internet access rate is high, ranging between 60–88 % for 4 BRICS economies, while India has a lower internet access rate of only 43 % (World Bank, 2021). So, financial companies have benefited by this large internet access of population and promoted their financial services, offering many innovative solutions into this field.

Another factor stimulating fintech development on the BRICS markets is represented by the rapid growth of e-commerce, retail e-commerce displaying higher rates in these countries (9,04%–11,8 %) comparing to the global average level (9 %) (Statista, 2024). Also, BRICS authorities implemented a sound regulatory environment for promoting fintech innovations and adoption on these markets and that stimulated hard competition in the fintech sector which increased accessibility of fintech services for population and companies (Elizaveta & Tjaša, 2020). In addition, Fig. 1 shows the course of the fintech index for BRICS countries in the period of 1992–2021. At a first glance, it appears that Russia was the most developed country in terms of fintech at the beginning of the observed period. On the other hand, it is observed that Russia has not been able to adequately adapt financial technologies in the process and therefore has fallen behind compared to other countries. Although it has low index values at the beginning of the process in financial technology, Brazil is also showing significant development. Another striking point is that while there was a rapid progress in financial technologies after 2000 for all BRICS countries, almost all countries experienced a negative break after the 2008 global financial crisis.

The possible contributions of the study to the literature are as follows: i) This study is expected to contribute to the literature as it is the first study to investigate the effects of financial technologies on environmental quality for BRICS countries. ii) The study brings a different perspective to the literature by investigating whether companies that offer fintech solutions as a solution to greenwashing have a greenwashing problem in themselves. iii) By using the load capacity factor as an environmental quality indicator, an indicator that more clearly represents the environment is used. iv) By using the quantile-on-quantile regression (QQR) technique in empirical analyses, detailed inferences are made by investigating the interactions for different quantiles of both fintech and environmental quality. v) In order to test the robustness of the findings, the marginal effects of fintech on the environment are also observed by using the Kernel-based Regularized Least Squares (KRLS) approach.

Empirical Literature Review

While reviewing the literature, we focus on studies that investigate the environmental impacts of fintech against the greenwashing problem that can pose an obstacle to the financial sector's contributions to environmental sustainability. First of all, in the context of firm-level studies, Vergara and Agudo (2021) investigated the success of two fintech initiatives in improving companies' deceptive processes such as greenwashing and concluded that fintech makes financial businesses more sustainable from a consumer protection perspective. Similarly, Guo et al. (2023) found that fintech reduces firm level pollution for Chinese industrial companies.

On the other hand, country-based analyzes have been included in studies on the fintech-environment relationship. These studies are mainly China-focused. For example, Tao et al. (2022) investigated the effects of fintech on greenhouse gas emissions on a global scale with 2018 data and used the fintech index as a fintech indicator. According to the findings from this study, fintech development contributes to the environment. Similarly, Song and Hao (2024); Li et al. (2024) and Guo et al. (2024) determined the reducing effect of fintech on carbon emissions for China. Moreover, due to the abundance of national-scale data sets on fintech for China, research has been conducted at the provincial level. Namely, Qin et al. (2024) investigated the effect of digital fintech index on the green environment index for 30 provinces of China and concluded that fintech contributes to environmental sustainability. Similarly, Muganyi et al. (2021) determined the sulfur dioxide reducing effect of the fintech index for 290 cities of China. Liu et al. (2025) explored the environmental impact of fintech for China and argued that increasing fintech reduces emissions (vice versa).

Although the environmentally friendly effects of fintech are detected in studies based on China, it is seen that the results change in quantile-based studies. For example, Liu et al. (2024a) investigated the effect of fintech on carbon emissions for China using quantile-based techniques, and as a result of empirical analysis, it was found that fintech was ineffective at low quantiles of emission level, but fintech reduced environmental damage at high quantiles of emission level. Similarly, Yang et al. (2024) investigated the relationship between fintech and ecological footprint using the QARDL technique for China, and as a result of empirical analysis, fintech reduces environmental degradation at high quantiles of ecological footprint, while fintech is ineffective at low quantiles of ecological footprint. Feng et al. (2024) used the QARDL technique for China and concluded that fintech reduces carbon emissions only in high quantiles of emissions.

In multi-country studies, it is seen that the focus is mainly on BRICS countries, including China. Udeagha and Ngepah (2023) investigated the effects of green finance and fintech on carbon emissions for BRICS countries with the CS-ARDL technique and concluded that fintech reduces the emission level in both the short and long term. Lu et al. (2023) investigated the relationship between fintech and carbon emissions for BRICS countries using techniques that observe the asymmetric relationship and concluded that fintech positive shocks lead to negative shocks of carbon emissions. In studies with BRICS samples, it is seen that the results differ in quantile-based analyses. For example, Wei et al. (2024) investigated the impact of fintech on carbon emissions for BRICS countries with quantile-based techniques and found that fintech reduces emissions in high quantiles of emissions, as opposed to the ineffectiveness of fintech in low quantiles of emissions.

Additionally, Muhammad et al. (2022) investigated the effects of financial technology and high-tech industry on environmental efficiency for EU countries and concluded that while financial technology increases environmental efficiency, high-tech industry harms environmental efficiency. Firdousi et al. (2023) concluded that fintech contributes to environmental quality for 26 developing countries. Using the ecological footprint as an indicator of environmental degradation against studies based on carbon emissions, Xia and Liu (2024) concluded that fintech development reduces the ecological footprint for G-7 countries. For developed countries, Sun et al. (2025) observed the environmental influence of fintech for G-20

countries and concluded that its effect changes based on the quantiles of environmental degradation.

In the above studies, the beneficial effects of fintech on the environment were mainly detected, but in quantile-based studies, it is seen that the effect in question occurs at high quantiles of environmental pollution. Despite this widespread view, there are also studies identifying the harmful effects of fintech on the environment. Lisha et al. (2023) investigated the relationship between fintech and carbon emissions for BRICS countries with the MMQR technique and, as a result of empirical analysis, concluded that fintech increases emissions in all quantiles and harms the environment. Similarly, Liu et al. (2024b) investigated the long-term effects of fintech on carbon emissions for China and Vietnam and concluded that fintech harms the environment in the long term. In addition, Okere et al. (2025) checked the influences of fintech on environment for North Africa and the results from long-run estimation technique show that fintech does not have significant effect on environment. However, the environmental quality supported impact has become valid only in higher quantiles.

If previous studies are evaluated in the context of which research gap this study fills, we must first focus on the environmental indicator used. It is seen that previous studies mainly focused on some emission pollution indicators and a limited number of studies focused on ecological footprint. On the other hand, in this study, a more detailed analysis based on the load capacity factor indicator, which also takes into account the ecological footprint but also the supply side of the environment, closes an important gap in the literature. On the other hand, the variation in findings in quantile-based studies indicates that the findings change as the extent of environmental pollution changes. However, simply controlling environmental quantiles may be insufficient. As a matter of fact, ignoring the quantiles of fintech in the studies in the literature is an important research gap. In order to close this gap, considering both the different quantiles of fintech and the different quantiles of the environment can be presented as an important empirical contribution in this study.

Data Description and Methods

The target variable of this study is environmental sustainability and the factor variable is fintech (FT) developments. This study measures environmental sustainability by the load capacity factor (LF) following the recent literature (for example, see Caglar *et al.*, 2024 & b; Ozkan *et al.*, 2023; Sun *et al.*, 2023; Yang *et al.*, 2023a). We calculate the LF of BRICS countries as $\frac{BIOPC}{EFPC}$, where $BIOPC$ and $EFPC$ represent the per capita biocapacity and per capita ecological footprint, respectively. The $BIOPC$ and $EFPC$ data series were retrieved from GFN (2024). Furthermore, we measure the FT developments of BRICS countries by utilizing the financial development index (FDI) as suggested by Lu et al. (2023). The utilized FDI contains nine indices that summarize how developed financial institutions and financial markets are in terms of their depth, access, and efficiency. These indices are aggregated into an overall index of financial development. The FDI data for BRICS countries were downloaded from IMF (2024). The sample period for this study is 1992–2021 as the $BIOPC$ and $EFPC$ data are available for Russia from 1992 and the FT data are available for BRICS countries until 2021. To address the problem occurred from the small sample size, we transformed the calculated LF and obtained FT data series of BRICS countries into quarterly series from 1992Q1 to 2021Q4 by using the quadratic→match→sum steps as in the studies of Razzaq et al. (2021), Abbasi et al. (2022), Ali et al. (2023), and Olasehinde-Williams et al. (2023).

In line with the structures of the LF and FT data series and of their relationship (see 4.1 and 4.2), this paper investigates the influence of fintech on environmental sustainability in BRICS countries employing the quantile-on-quantile regression "QQR" methodology introduced by Sim and Zhou (2015). The QQR is a time-series methodology that allows practitioners to analyze the QQ impact of a factor variable on a target variable as it considers the quantiles of both the target and factor variables. In this paper, the QQ impact of FT on LF in BRICS countries is investigated by employing the following five QQR models:

$$QQR(BRALF|BRAFT) = \delta_1(BRALF^q, BRAFT^q) + QQ_1(BRALF^q, BRAFT^q)(BRAFT - BRAFT^q) \quad (1)$$

$$QQR(RUSLF|RUSFT) = \delta_2(RUSLF^q, RUSFT^q) + QQ_2(RUSLF^q, RUSFT^q)(RUSFT - RUSFT^q) \quad (2)$$

$$QQR(INDLF|INDFT) = \delta_3(INDLF^q, INDFT^q) + QQ_3(INDLF^q, INDFT^q)(INDFT - INDFT^q) \quad (3)$$

$$QQR(CHNLF|CHNFT) = \delta_4(CHNLF^q, CHNFT^q) + QQ_4(CHNLF^q, CHNFT^q)(CHNFT - CHNFT^q) \quad (4)$$

$$QQR(ZAFLF|ZAFFT) = \delta_5(ZAFLF^q, ZAFFT^q) + QQ_5(ZAFLF^q, ZAFFT^q)(ZAFFT - ZAFFT^q) \quad (5)$$

In Eqs. 1 to 5, q represents the quantiles that ranges from 0.1, 0.15, …, 0.85 and 0.9, δ's demonstrate the QQR constant, and QQ's denote the QQR slope.

As in the extant literature (see, e.g., Adebayo *et al.*, 2023; Alola *et al.*, 2023; Kartal *et al.*, 2023; Pata *et al.*, 2024; Sinha *et al.*, 2021), we utilize the quantile regression "QR" method of Koenker and Bassett (1978) as a robustness of the QQR results. By focusing on the quantiles of the target variable, the QR shows the quantile impact of a factor variable on a target variable. We utilize the following QR models to analyze the quantile impact of FT on LF in BRICS countries:

$$QR(BRALF|BRAFT) = \gamma_1(BRALF^q) + Q_1(BRALF^q)(BRAFT) \quad (6)$$

$$QR(RUSLF|RUSFT) = \gamma_2(RUSLF^q) + Q_2(RUSLF^q)(RUSFT) \quad (7)$$

$$QR(INDLF|INDFT) = \gamma_3(INDLF^q) + Q_3(INDLF^q)(INDFT) \quad (8)$$

$$QR(CHNLF|CHNFT) = \gamma_4(CHNLF^q) + Q_4(CHNLF^q)(CHNFT) \quad (9)$$

$$QR(ZAFLF|ZAFFT) = \gamma_5(ZAFLF^q) + Q_5(ZAFLF^q)(ZAFFT) \quad (10)$$

In Eqs. 6 to 10, γ's represent the QR constant and Q's indicate the QR slope.

For additional robustness, the study also employs the kernel-based regularized least squares "KRLS" methodology of Hainmueller and Hazlett (2014) and Ferwerda et al. (2017) following Ojonugwa et al. (2023). The KRLS demonstrates the marginal effects of any number of factor variables on each observation of the target variable. The marginal effects of FT on LF in BRICS countries are examined by using the following KRLS models:

$$KRLS(BRALF|BRAFT) = M_1(BRAFT) + \varepsilon_1 \quad (11)$$

$$KRLS(RUSLF|RUSFT) = M_2(RUSFT) + \varepsilon_2 \quad (12)$$

$$KRLS(INDLF|INDFT) = M_3(INDFT) + \varepsilon_3 \quad (13)$$

$$KRLS(CHNLF|CHNFT) = M_4(CHNFT) + \varepsilon_4 \quad (14)$$

$$KRLS(ZAFLF|ZAFFT) = M_5(ZAFFT) + \varepsilon_5 \quad (15)$$

In Eqs. 11 to 15, M's denote the average marginal effects ant and ε's represent the standard error. Note that the average marginal effects are the average of the marginal effects of FT on each observation of LF.

The flowchart of the study's employed methodologies is summarized in Figure 2.

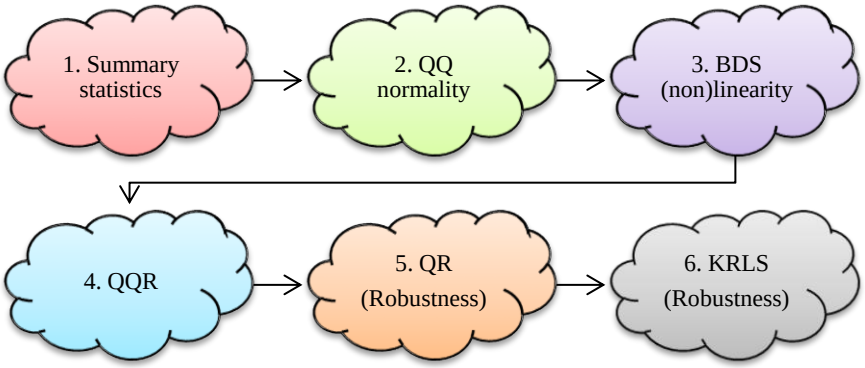


Figure 2. Flowchart of Methodologies Employed

Empirical Results

Summary Statistics and QQ Normality Plots

Table 1 demonstrates the summary statistics of the BRICS counties' quarterly LF and FT data series from 1992Q1 to 2021Q4. As can be seen that BRA has the highest average environmental sustainability and fintech developments. On the other hand, CHN and IND have the lowest average environmental sustainability and fintech developments, respectively. Similarly, in the sample period, BRA has the highest LF and FT volatility, whereas ZAF and IND have the lowest LF and FT volatility, respectively.

Table 1

Summary Statistics for the LF and FT Data Series

	BRA LF	RUS LF	IND LF	CHN LF	ZAF LF
Mean	0.864	0.320	0.102	0.083	0.102
Median	0.871	0.326	0.100	0.075	0.097
Maximum	1.111	0.356	0.133	0.131	0.127
Minimum	0.716	0.246	0.081	0.056	0.085
Std. Dev.	0.103	0.020	0.016	0.025	0.012
	BRA FT	RUS FT	IND FT	CHN FT	ZAF FT
Mean	0.129	0.118	0.110	0.121	0.115
Median	0.140	0.120	0.109	0.121	0.120
Maximum	0.167	0.145	0.137	0.169	0.148
Minimum	0.063	0.082	0.076	0.070	0.068
Std. Dev.	0.031	0.016	0.012	0.028	0.024

In this study, we analyze the normality of the LF and FT data series' distributions for the BRICS countries by utilizing the QQ normality (QQN) plots as in the studies of Demirel and Unal (2020), Sinha et al. (2020), Cheng et al. (2021), Alfeus and Collins (2023), and Wang et al. (2023a). It can be seen from the QQN plots illustrated in Figure 3 that all the quarterly LF and FT data series from 1992Q1 to 2021Q4 have an asymmetric (or nonlinear) distribution. The fact that the LF and FT data series have an asymmetric (or nonlinear) distribution, reveals that any of the linear econometric methods cannot be applied on these data series.

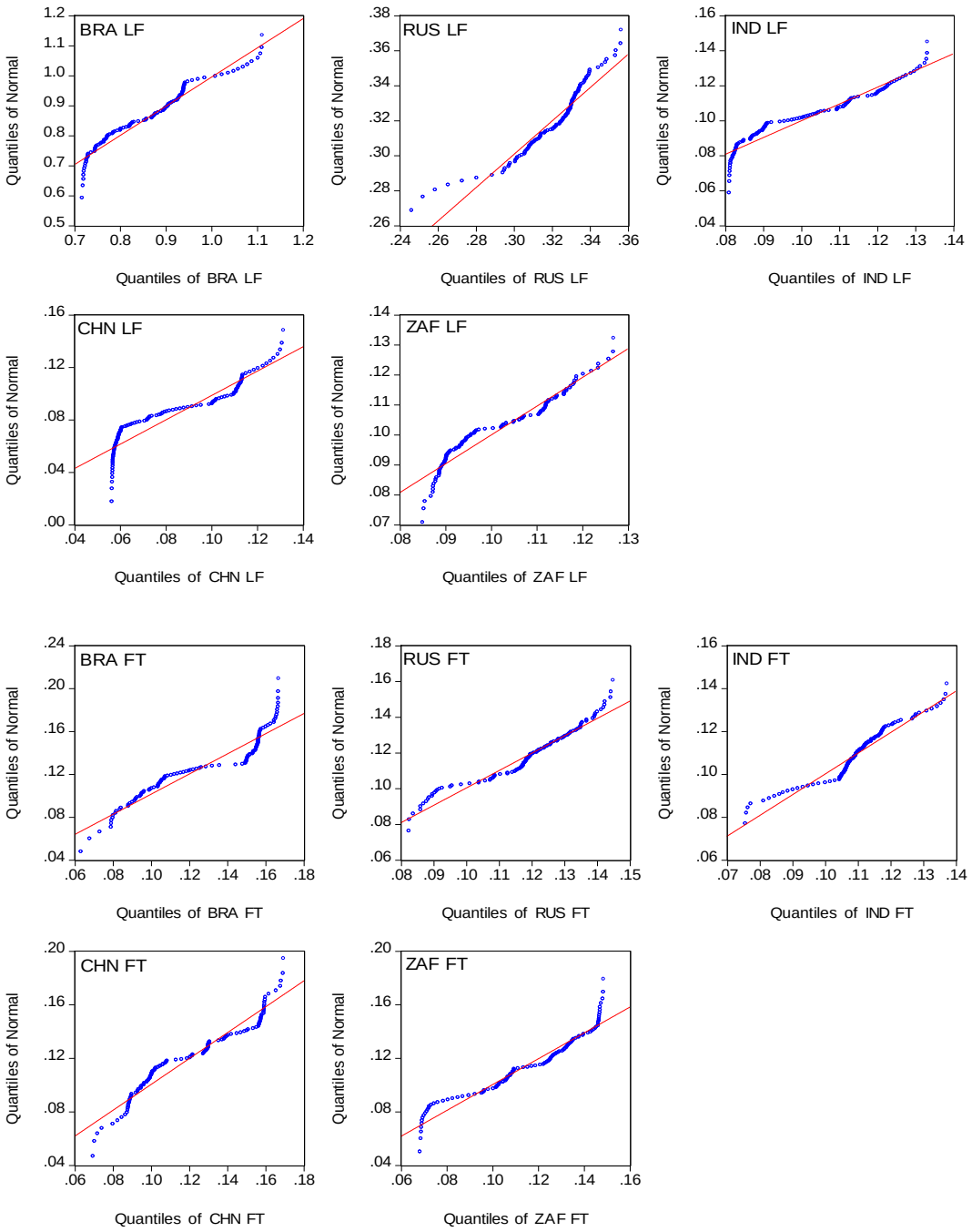


Figure 3. QQ Normality Plots for the LF and FT Data Series

The Results of (Non)Linearity Analysis

The study employ the BDS test proposed by Broock et al. (1996) to examine the structure of the relationship between FT and LF in BRICS countries as in the studies of Depren et al. (2021) Gherghina and Simionescu (2023), Kartal and Depren (2023), Pata et al. (2023), and Adebayo and Özkan (2024). More specifically, we employ the BDS methodology on the residuals of the VAR(1) models established between FT and LF for each BRICS countries. The obtained BDS estimates are provided in Table 2. The estimates indicate that the null hypothesis that residuals are i.i.d. is rejected for all embedding dimensions from 2 to 6 in BRICS countries. This result showcases that the relationship between FT and LF in BRICS countries presents nonlinearity and therefore the linear econometric methods are not appropriate for this study.

Table 2

BDS Test Results for the VAR(1) Residuals

Embedding Dimensions	BRA	RUS	IND	CHN	ZAF
2	5.161***	7.641***	5.355***	2.455**	7.593***
	0.000	0.000	0.000	0.014	0.000
3	4.987***	5.855***	5.503***	1.771*	6.693***
	0.000	0.000	0.000	0.076	0.000
4	6.509***	4.832***	6.433***	2.248**	7.081***
	0.000	0.000	0.000	0.024	0.000
5	9.107***	6.578***	7.892***	4.142***	10.702***
	0.000	0.000	0.000	0.000	0.000
6	12.433***	8.038***	9.138***	5.612***	15.551***
	0.000	0.000	0.000	0.000	0.000

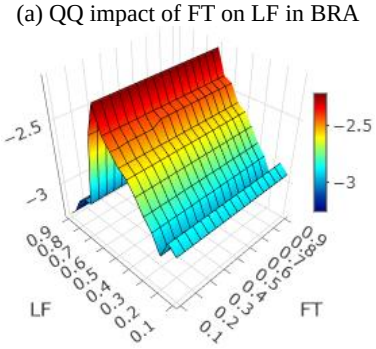
*Note: *** p < 0.01, ** p < 0.05, and * p < 0.1.*

The Results of Quantile-on-Quantile Regression

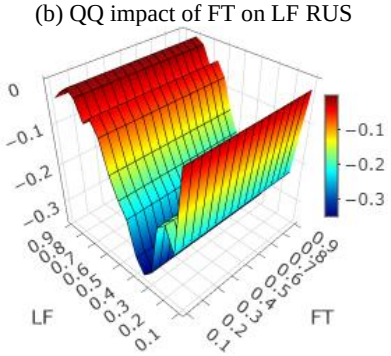
In line with the main purpose of the research, at this stage, the effects of fintech on the load capacity factor are investigated with the QQR technique and the findings are presented in Figure 4. According to the findings for Brazil, progress in financial technology negatively affects environmental quality in all quantiles. Moreover, the negative effect in question does not vary according to the quantiles of fintech. On the other hand, it is concluded that the negative impact of fintech on the environment increases in low and high quantiles of environmental quality.

According to the inferences made from Figure 4b, a similar situation is valid in Russia. The increase in fintech negatively affects the environmental quality in Russia, although not as much as in Brazil. Here too, changes in the level of fintech do not significantly change the impact, but the negative impact of fintech on the environment is greater, especially in the low and middle quantiles. As environmental quality increases, the harmful effects of fintech on the environment almost disappear.

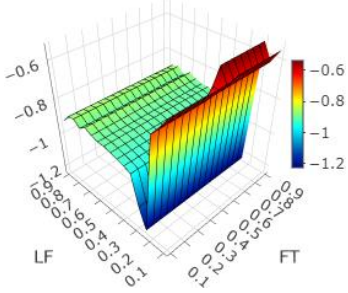
(a) QQ impact of FT on LF in BRA



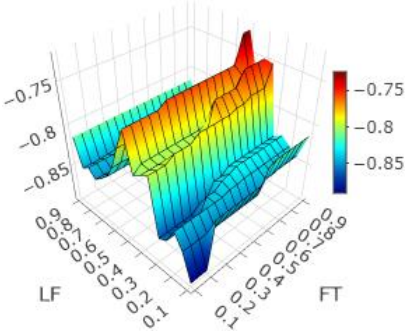
(b) QQ impact of FT on LF RUS



(c) QQ impact of FT on LF in IND



(d) QQ impact of FT on LF in CHN



(e) QQ impact of FT on LF in ZAF

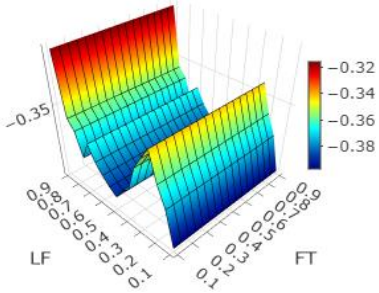


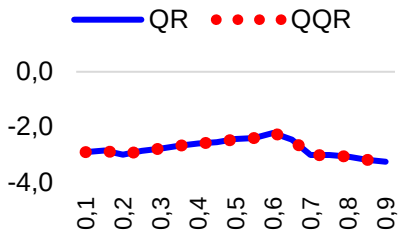
Figure 4. Quantile-on-Quantile Impact of FT on LF in BRICS Countries

In case of Figure 4c, it is concluded that fintech in India harms the environment in all evidence. Despite environmental quality is low, the harmful effects of fintech are also low. However, as environmental quality increases, the harmful effects of fintech also increase. The environmental impacts of fintech for China can also be seen in Figure 4d. Accordingly, the increase in fintech reduces the load capacity factor in all quantiles. At higher quantiles of fintech, the harmful impact on the environment decreases. On the other hand, the harmful effect of fintech on environmental quality increases in the lower and upper quantiles of environmental quality. Finally, according to the data presented in Figure 4e for South Africa, fintech harms environmental quality in all quantiles. Additionally, like other countries, fintech quantiles do not play a significant role in this impact. In contrast, at higher quantiles of environmental quality, the harmful effect of fintech on environmental quality decreases slightly.

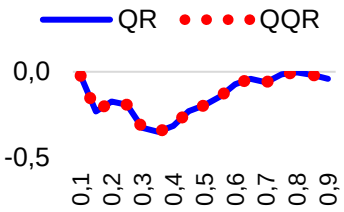
Robustness check (QR and KRLS)

Different techniques are also used to test the reliability of the findings obtained as a result of the QQR analysis in the previous stage. In this context, the results obtained by comparing the average quantile regression (AQQR) coefficients with the classical quantile regression (QR) coefficients are presented in Figure 5. According to the findings, QR coefficients and AQQR coefficients are significantly similar. Additionally, the negative impact of fintech on environmental quality has been validated for all BRICS countries. That is, while the harmful effects of fintech on load capacity weaken in the middle quantiles of environmental quality for Brazil and China, the harmful effects for Russia and India increase further in the middle quantiles. This inference is supported by both QR and average QQR coefficients.

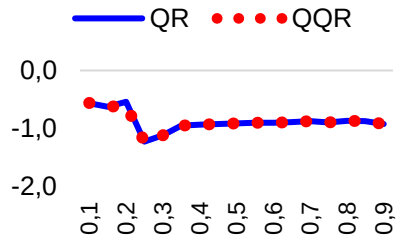
(a) Quantile impact of FT on LF in BRA



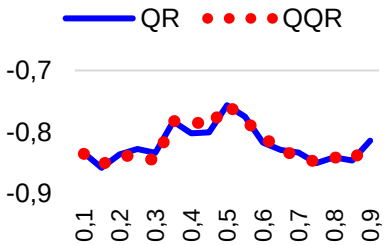
(b) Quantile impact of FT on LF in RUS



(c) Quantile impact of FT on LF in IND



(d) Quantile impact of FT on LF in CHN



(e) Quantile impact of FT on LF in ZAF

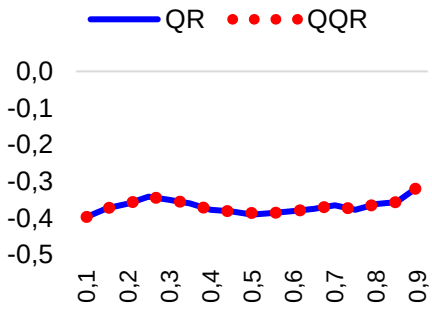


Figure 5. Quantile Impact of FT on LF in BRICS Countries

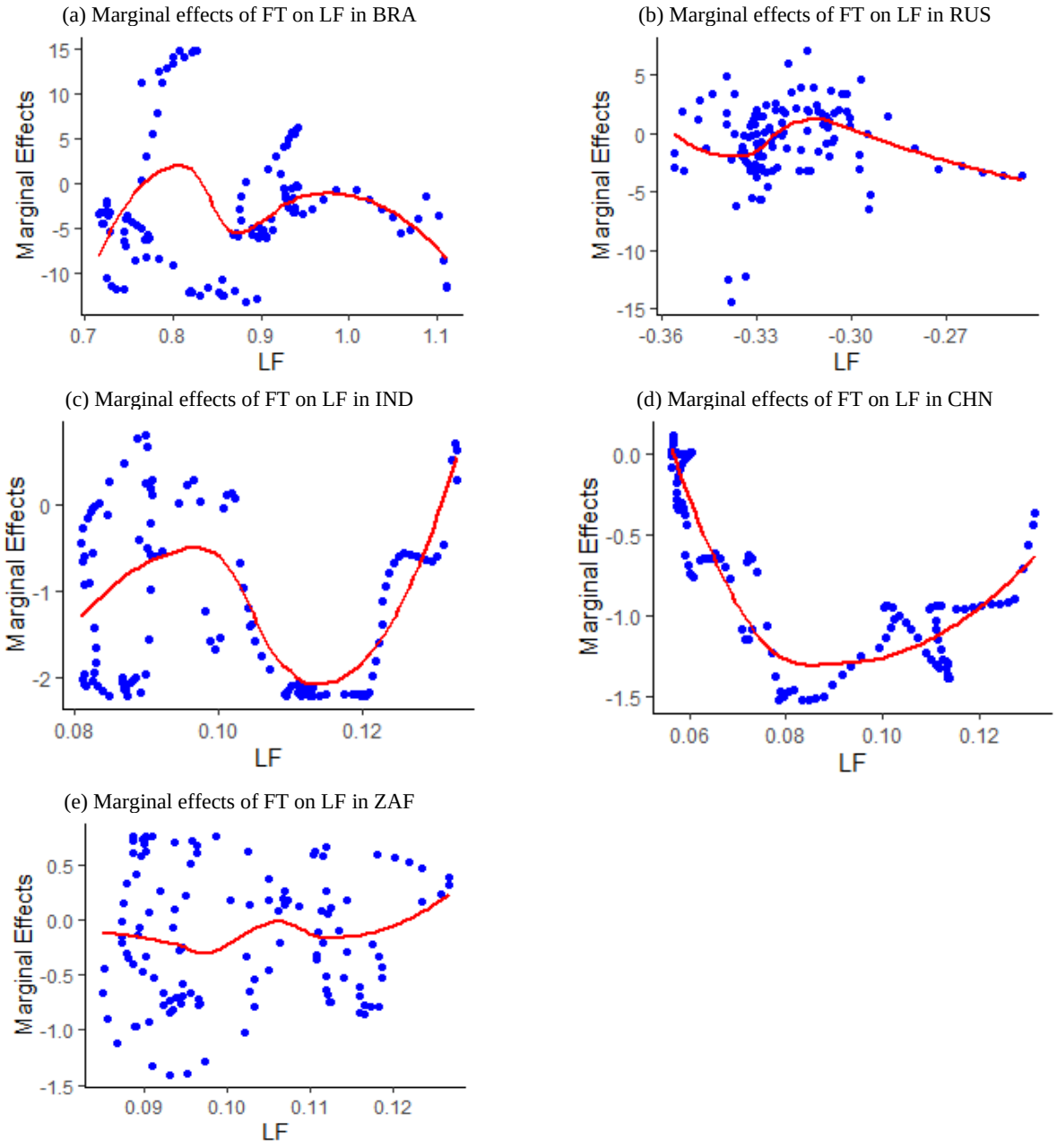


Figure 6. Marginal Effects of FT on LF in BRICS Countries

Table 3

Average Marginal Effects of FT on LF in BRICS Countries

	Ave	SE	t	p	0.25	0.5	0.75
BRA	-2.481***	0.411	-6.033	0.000	-6.007	-3.792	-0.406
RUS	-0.646***	0.196	-3.285	0.001	-2.703	-0.285	1.669
IND	-1.162***	0.145	-7.984	0.000	-2.099	-1.410	-0.426
CHN	-0.714***	0.043	-16.483	0.000	-1.137	-0.827	-0.118
ZAF	-0.154***	0.058	-2.639	0.009	-0.672	-0.205	0.316

*Note: *** p < 0.01.*

In the final stage, the findings obtained from the empirical analyzes are investigated with the Kernel-based Regularized Least Squares technique, which is based on a machine learning-based algorithm, and the findings are presented in Figure 6. According to this analysis, the point marginal effects of fintech on environmental quality can be calculated. Additionally, as environmental quality increases, it can be observed how the effects of fintech growth change. Accordingly, for Brazil, Russia and China, the marginal returns of fintech on environmental quality are almost always negative. On the other hand, for India and South Africa, after a certain level of environmental quality is reached, the harmful effects of fintech disappear and the return turns positive, although the impact is low. These findings are summarized in Table 3.

Discussions

According to the achieved results, fintech negatively impacts on environment in all BRICS countries. For India and South-Africa the negative impact displays the same magnitude in all quantiles. For China, Russia and Brazil, the negative impact of fintech on environment varies on different quantiles. However, according to the results of KRLS estimations measuring the average marginal effect of fintech on environment, in India and South-Africa this effect can turn to positive values after achieving a certain level of environmental quality. For the other three countries, even after this point, the values still remain negative.

The impact of fintech on environment depends on green technological innovations, economic growth, industrial structure of the country and financial constraints (Cheng *et al.,* 2023; Lee & Wang, 2022; Wang *et al.,* 2022). Also, it depends on the coordination between financial and environmental policies and cooperations between different governmental agencies and institution for achieving green innovation (XU &Kim, 2022). China's fintech adoption rate is 87 %, ranking on first position into the world comparing to a global adoption rate of 64 % (Amstad *et al.,* 2020) and some studies proved that fintech support climate regulations and policies in their goal of reducing carbon emissions in China, but the effect is heterogenous among cities and regions in China, and the effect is significantly positive in non-resources-based cities and regions (Ni *et al.,* 2023; Xue *et al.,* 2022). Mertzanis (2023) investigated an international panel of countries during 2013–2019 and found a rather small positive impact of fintech on environmental performance. fintech is associated with ESG scores and investing. Wang et al. (2022) emphasized that fintech can support the increase of availability of ESG information and reduce the cost associated with ESG investments, but they underlined the lack of ESG uniform reporting and reliability of ESG information that can spur the positive impact of fintech on ESG reporting and investments (Ehlers *et al.,* 2021). The positive impact of fintech on environment can be rather observed in the developed economies, where fintech infrastructure is already established, the financial funds are available and the market regulations exist and they are efficient and functional (Zhou *et al.,* 2022; Xue *et al.,* 2022). In the developing nations these conditions are not fully met, so the positive impact of fintech is not obvious because financial innovations require high electricity consumption and fossil-fuels energy that increase carbon emissions (Tao *et al.,* 2022). Afjal et al. (2023) haven't found also a discernable impact of financial technology on carbon emissions for emerging and growth-leading economies during 2005–2020, although the internet use proved to reduce carbon emissions. Shahzani et al. (2019) showed that the impact of financial technology varies across economic sectors in Iran. In agriculture and industrial sectors, financial technologies increased pollution with negative effects on environment. Silva (2018) has demonstrated that fintech can support economic growth and green innovations only if the macroprudential measures are strengthen. Also, Afjal et al. (2022) proved that association between fintech and energy markets doesn't hold in the long-run, so the impact of fintech on energy consumption is not clear in the long-term.

Due to many available data for fintech in China, and high adoption rate of financial technologies there, many previous studies (Yang *et al.,* 2024), Feng *et al.,* 2024), Liu *et al.,* 2024a) investigated the relation between fintech and carbon emissions using quantile regressions and found that fintech is efficient for reducing carbon emissions only in high quantiles. Other studies elaborated for BRICS economies found the same results (Wei *et al.,* 2024). So, even into the studies that identified an overall positive impact of fintech on the environment, quantile analysis displayed greater impact for upper quantiles and inefficiency of fintech in lower quantiles. Muhammad et al. (2022) have demonstrated that high-tech industry has a negative impact on pollution for EU countries. Other studies using MMQ technique found an adverse impact of fintech on environment for BRICS countries or other developing nations (Lisha *et al.,* 2023; Liu *et al.,* 2024b). Thus, our findings are confirmed both by developed and developing nations, though the results may vary across different quantiles. Still, since it is a quantile analysis, the best match for our results and policy recommendations would be for developing nations with a similar development level of financial industry and same level of financial innovation or financial sophistication. Also, they should present a similar regulatory framework regarding financial industry, because developed markets display a very sound and highly functional financial market and financial and environmental regulations.

Due to a rapid development of Fintech industry during the last decade all over the world, authorities should focus on better regulating this industry, regulating the adoption of digital financial platform and financial operations. ESG reporting should become mandatory for financial sector, while taxing greenwashing attitudes and fake reporting should become stricter and harder. Financial support should be large for green finance products and green finance innovations, in a more regulated framework of Fintech industry. Also, financial funds should be invested in clean energy sector to support an increased energy consumption in the Fintech era, without larger pollutant emissions. In Banking and Financial Industry, the ESG incidents related to misleading communication on pollution and climate change still represents 15 % of total ESG incidents, ranking on 2nd position after Oil and gas sector with a share of 19 %. In 2023, the financial industry faced a 70 % increase of greenwashing incidents. Governance, processes, and policies must be updated to cover risk management operations. ESG reports must be checked through periodical controls (KPMG, 2024). The establishment of independent ESG rating and certification systems could further enhance the credibility of ESG scores in the fintech sector. These ratings can serve as a reliable tool for investors to differentiate between genuinely sustainable firms and those engaging in superficial ESG activities.

Still, in practice it is rather difficult for financial products to comply with regulations in place in different regions. Although the authorities are trying to address greenwashing by increased transparency, their regulations vary a lot. While the ESG statements in US are rules-based, the in EU they are more principles-based (and they face many revisions). Some US regions even adopted ESG legislation by themselves. Tin UK, Sustainability Disclosure Requirements are not very similar with neither US or EU regulations in this area (KPMG, 2024). Thus, there are many differences across

countries, regions in terms of ESG disclosures statements and continuous evolving financial market and financial innovations makes things even harder for regulators.

Thus, our results are validated by previous studies performed for BRICS nations or for other developing countries. The impact of financial technologies on environment depends on the time frame, on the availability of financial funds allocated for green technological innovations, on industrial structure of the developing economies, on economic growth rate, on natural resources dependence rate, on the existence of developed financial infrastructure and functional and efficient implementations of environmental and prudential regulations in the financial industry. These pre-conditions are not met in the BRICS economies considering our achieved results showing a negative impact of fintech in all quantiles for all these investigated countries. Still, for India and South-Africa, this impact can change in the long-run according to the analysis of the marginal impact. There are also necessary efforts to make ESG reports more uniform and reliable and greenwashing initiatives should be sanctioned and totally discourage through adequate regulations. Otherwise, fintech can't positively contribute to proper and transparent disclosure of information necessary for the investors in the market and for consumers, so that the fintech can positively contribute to protecting the environment. BRICS rapid growth based on industrial sectors determined a large energy consumption and although they made significant progress on adopting renewable energy sources and using nuclear energy, they still reply on fossil fuels that are heavily pollutant. Russia and South Africa rely on natural resources extraction which also negatively affects environment in these economies. Although they display high fintech adoption rates and large access to the internet, energy consumption is high. They benefit of international financial aid from the developed economies, but they should allocate more funds for green investments to alleviate environmental burden and increase energy efficiency and security. They should also reinforce a tight environmental regulation frame for financial and non-financial companies in order to benefit for financial funds for green innovations, otherwise greenwashing activities will prevail and negatively impact on the environment and on sustainable development of BRICS economies. As we could have noticed from the quantile estimations, once the environmental quality increases, the fintech negative significantly decreases in Russia, China and South-Africa. Thus, once the regulatory environment will strengthen, that will mitigate the negative impact of fintech on environment though fewer fossil fuels consumption, and more investments in green technologies.

Conclusions and Policy Recommendations

In the current research, we have investigated the nexus between fintech and environmental quality (with load capacity factor as a proxy, for showing both supply and demand side environmental aspects) based on quarterly data for BRICS economies during 1992Q1 to 2021Q4. BRICS display highest fintech adoption rates into the world and they are developing countries with robust growth rates. Still, their economies reply wither on industry, mainly manufacturing industrial sectors, or based on natural resources extraction industries, which made those countries among top pollutant economies of the world. However, they achieved great progress on reducing their carbon emissions and on energy transition path, through implementing regulatory measures in the environmental area and through investments in the renewables sector.

We have applied BDS test for checking the (non)linear relation between fintech and LCF and we have found a nonlinear association which validated a quantile analysis through QQR. We have validated QQR results through applying QR estimations as robustness test. Then we have applied KRLS approach for studying marginal effect of fintech on LCF into BRICS economies. Our results show that fintech negatively impacts on environment in all BRICS nations. For India, South-Africa and even Brazil, the negative impact can be noticed in all quantiles with same magnitude, while for Russia and China the magnitude of the negative impact varies across quantiles. In higher quantiles, the negative impact of fintech decreases, while in lower quantiles it increases. However, for India and South-Africa the marginal effect analysis shows that after reaching a certain point of environmental degradation, the impact of fintech on environment turns to positive values. For China, Russia and Brazil, the impact of fintech stays negative.

As we have pointed out above, the impact of fintech on environment depends on some important factors such as structure of the economy and all these investigated countries are industrialized countries with a high reliance of fossil fuels and on natural resources extraction. Also, robust economic growth rates required an increased energy consumption. Fintech high adoption rate also required high electricity consumption. These countries are highly integrated into the global chain network and their trade openness is high. Their exports rely on manufactured products and natural resources. All these factors negatively affected environment and fintech couldn't reach the point where it can alleviate environmental burden because of insufficient financial funds allocated for green innovations and clean technologies, or an inefficient use of these financial funds for green activities. The lack of a proper regulatory environment seems to be the main cause for this significant negative effect of financial services on environment in BRICS economies. They are leading countries in terms of economic growth, but with all the achieved progress made on energy transition path and for carbon neutrality target, this is not enough. The example of China, top pollutant country is undeniable. China implemented strict control and command environmental based regulations for limiting emissions and market based environmental regulations to tax polluters in order to overcome its environmental problems. It also allocated large financial funds for research and development in the energy area and for stimulating technological innovations. All these measures proved their efficiency in reducing pollution and in supporting clean energy consumption. However, much progress should be achieved in implementing mandatory and uniform ESG reporting not only in China, but also in the other BRICS economies. This way, private companies wouldn't be able to hide their real intentions and their activities performed in the environmental area. Fintech can support a larger access to information, but this information should be real and uniform among all companies so that the investors and consumers can compare and choose being

totally well informed. Companies that don't promote green activities will be sanctioned by investors and consumers and will suffer in terms of market value and in terms of financial profitability. Authorities should also introduce high tax and strict sanctions against companies that don't respect environmental regulations and don't properly report their efforts for environmental sustainability. BRICS countries benefit of large financial aid from the developed economies and financial funds should be primarily oriented to sectors that promote measures for environmental protection and authorities should grant state guarantees for these financial loans. Also, authorities should stimulate allocation of larger financial funds for research and development even in private-public partnerships. Fintech has a large adoption rate in BRICS economies as rapid developing economies and as a result of large international financial aid received from the developed economies. However, that should be accompanied by a more efficient use of these funds, through an adequate monitoring of the use of these funds and through implementing mandatory and uniform ESG reporting of the companies. Granting incentives for an efficient use of financial funds for achieving the environmental goals and energy transition, and sanctioning the activities that harm environment or fake reporting of corporate initiatives should prevent greenwashing and will support a positive impact of financial technologies on the environment into the future. Financial technologies rapid development has changed the world financial landscape during the last decade. Adoption of financial technologies will increase all over the world, but through adequate implemented measures and a strict regulatory framework into the developing countries, their impact on environment will be positive just like the experience of the developed economies has shown us. Financial and environmental policies should be coordinated. Authorities should set environmental standards for industries in order to get financing for green projects and activities. They should also supervise these green projects and ensure proper disclosure of the green corporate activities. Governments should support financial development for green projects meaning they should support the use of digital technologies by private financial and non-financial corporations in order to receive finance for green projects.

Some efforts have been made to fight against greenwashing in BRICS economies. In March 2023, China adopted enforced misleading practices in advertising. Punishment mechanism for greenwashing practices has led to significant progress to avoid greenwashing in China, but subsidies granted for green innovation couldn't suppress greenwashing practices (Sun & Zhang, 2019). So, taxing greenwashing works better than financial support granted for Chinese corporations. Companies should not address vague environmental claims if they can't be demonstrated as being eco-friendly. Organizations buying carbon credits to decrease their environmental impact have to make that public. Europe and developed nations more generally (Zahid *et al.,* 2022) have seen significantly improved ESG disclosure area, while developing countries remain in early stages (Wang *et al.,* 2023b). In this regard, in March 2024, EU adopted Green Claims Directive which implements verification system for organizations that address environmental-related claims and EU intends to introduce new standards for making products more sustainable and eco-friendly. UK adopted green claims codes; US adopted green guides for environmental claims. These regulations can be adopted and adapted to BRICS countries also to avoid greenwashing practices.

For example, in China, in 2021, only 26 % of the listed companies disclosed their ESG reports and problems persist regarding unbalanced and inadequate ESG reporting (Yang *et al.,* 2023b). High costs of implementing ESG principles reduce companies' motivation to comply with ESG rules and thus, regulators and investors face great challenges in obtaining information to drive their investments (Zhang & Liu, 2022). Fintech companies, less regulated in terms of ESG standards, must prioritize the development of robust and verifiable ESG frameworks to align to sustainability claims. Authorities and Fintech industry standards must work together to establish clearer and more stringent guidelines for ESG reporting in the fintech sector. That can help ensure that ESG claims are backed by genuine practices and measurable outcomes, reducing for greenwashing practices.

China and Brazil achieved the greatest progress on this path, while India and Russia still have a lot to achieve. In China has focused on environmental and social considerations in regulating financial market, while Brazil targeted more business risk management. Legal steps were achieved in China and Brazil such as adopting Green Credit Guidelines in China. Central Bank of Brazil required mandatory environmental and social policies for all financial institutions there. Indonesia adopted Sustainability Reporting for Financial Institutions and the adequate framework for issuing green bonds. South Africa adopted sustainability regulations and for ESG disclosures for Stock exchange market, Johannesburg Stock Exchange.

BRICS economies should complement taxation with support incentives granted for green finance activities. That can include proper standards, and reporting requirements for using green bonds or green investments funds (Udeagha & Breitenbach, 2023a). Regulations should ensure transparency and a proper statement of risks in the environmental area. The BRICS authorities must settle a stimulatory regulatory framework to boost innovation and sustainable fintech practices. This includes designing rules for fintech corporations in the environmental area (Udeagha & Breitenbach, 2023b). They need to adopt digital payment technologies to rise efficiency, reducing material waste and facilitating sustainable investing.

A limitation of this study is including only financial technologies into the analysis. Future research should also focus on analyzing the impact of overall financial development and financial inclusion on environmental degradation, because financial development and financial inclusion is low among developing economies and even in BRICS economies many people don't have access to financial services or even to internet, so their lack of access to information and financing affects the ability of these economies to use financial technologies and services to overcome their environmental problems. Second limitation of this study is that the QQR does not account for cross-country dependencies in a panel setting and does not explicitly address endogeneity concerns. Future research could explore panel-based methodologies to complement

the insights provided by QQR. Third limitation of this study is that the QQR approach examines the relationship between two variables and does not consider how other variables may affect this relationship. Future research can be conducted using multivariate models that can eliminate the omitted variable bias of QQR.

References

Abbasi, K. R., Hussain, K., Haddad, A. M., Salman, A., & Ozturk, I. (2022). The role of Financial Development and Technological Innovation towards Sustainable Development in Pakistan: Fresh insights from consumption and territory-based emissions. *Technological Forecasting and Social Change*, 176, 121444. https://doi.org/10.1016/j.techfore.2021.121444

Adebayo, T. S., & Ozkan, O. (2024). Investigating the influence of socioeconomic conditions, renewable energy and eco-innovation on environmental degradation in the United States: A wavelet quantile-based analysis. *Journal of Cleaner Production*, 434, 140321. https://doi.org/10.1016/j.jclepro.2023.140321

Adebayo, T. S., Bekun, F. V., Rjoub, H., Agboola, M. O., Agyekum, E. B., & Gyamfi, B. A. (2023). Another look at the nexus between economic growth trajectory and emission within the context of developing country: Fresh insights from a nonparametric causality-in-quantiles test. *Environment, Development and Sustainability*, 25(10), 11397–11419. https://doi.org/10.1007/s10668-022-02533-x

Afjal, M., Kathiravan, C., Dana, L.P., & Nagarajan, C. D. (2023) The Dynamic Impact of Financial Technology and Energy Consumption on Environmental Sustainability. *Sustainability*, 15, 9327. https://doi.org/10.3390/su15129327

Afjal, M., & Sajeev, K. C. (2022). Interconnection between cryptocurrencies and energy markets: An analysis of volatility spillover. *OPEC Energy Rev*. 46, 287–309. https://doi.org/10.1111/opec.12227

Alfeus, M., & Collins, J. (2023). A novel stochastic modeling framework for coal production and logistics through options pricing analysis. *Financial Innovation*, 9(1), 54. https://doi.org/10.1186/s40854-022-00440-8

Ali, K., Jianguo, D., & Kirikkaleli, D. (2023). Driving toward a greener future: Green logistics, financial innovation, and environmental sustainability in China-evidence from novel Fourier approaches. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-023-04199-5

Alola, A. A., Ozkan, O., & Usman, O. (2023). Examining crude oil price outlook amidst substitute energy price and household energy expenditure in the USA: A novel nonparametric multivariate QQR approach. *Energy Economics*, 120, 106613. https://doi.org/10.1016/j.eneco.2023.106613

Amstad, M., Sun, G., & Xiong, W. (Eds.). (2020). The Handbook of China's Financial System. *Princeton University Press*. https://doi.org/10.1515/9780691205847

Broock, W. A., Scheinkman, J. A., Dechert, W. D., & LeBaron, B. (1996). A test for independence based on the correlation dimension. *Econometric Reviews*, 15(3), 197–235. https://doi.org/10.1080/07474939608800353

Caglar, A. E., Daştan, M., Bulut, E., & Marangoz, C. (2024). Evaluating a pathway for environmental sustainability: The role of competitive industrial performance and renewable energy consumption in European countries. *Sustainable Development*, 32(3), 1811–1824. https://doi.org/10.1002/sd.2755

Chen, R., Ramzan, M., Hafeez, M., & Ullah, S. (2023). Green innovation-green growth nexus in BRICS: does financial globalization matter?. *Journal of Innovation & Knowledge*, 8(1), 100286. https://doi.org/10.1016/j.jik.2022.100286

Cheng, C., Ren, X., Dong, K., Dong, X., & Wang, Z. (2021). How does technological innovation mitigate CO2 emissions in OECD countries? Heterogeneous analysis using panel quantile regression. *Journal of Environmental Management*, 280, 111818. https://doi.org/10.1016/j.jenvman.2020.111818

Cheng, X., Yao, D., Qian, Y., Wang, B., & Zhang, D. (2023) How does fintech influence carbon emissions: Evidence from China's prefecture-level cities, *International Review of Financial Analysis*, Volume 87, 102655, https://doi.org/10.1016/j.irfa.2023.102655

Chueca Vergara, C., & Ferruz Agudo, L. (2021). Fintech and sustainability: do they affect each other?. *Sustainability*, 13(13), 7012. https://doi.org/10.3390/su13137012

Das, N., Gangopadhyay, P., Alam, M. M., Mahmood, H., Bera, P., Khudoykulov, K., ... & Hossain, M. E. (2024). Does greenwashing obstruct sustainable environmental technologies and green financing from promoting environmental sustainability? Analytical evidence from the Indian economy. *Sustainable Development*, 32(1), 1069–1080. https://doi.org/10.1002/sd.2722

Demirel, M., & Unal, G. (2020). Applying multivariate-fractionally integrated volatility analysis on emerging market bond portfolios. *Financial Innovation*, 6(1), 50. https://doi.org/10.1186/s40854-020-00203-3

Depren, O., Kartal, M. T., & Kılıc Depren, S. (2021). Recent innovation in benchmark rates (BMR): Evidence from influential factors on Turkish Lira Overnight Reference Interest Rate with machine learning algorithms. *Financial Innovation*, 7(1), 44. https://doi.org/10.1186/s40854-021-00245-1

Ehlers, T., Gao, D. N., & Packer, F. (2021). A taxonomy of sustainable finance taxonomies. No 118 in BIS Papers from Bank for International Settlements, October 2021. Retrieved from https://www. bis.org/publ/bppdf/bispap118.pdf; https://doi.org/10.2139/ssrn.3945635

Elizaveta, G., & Tjasa, I. (2020). Regulatory sandboxes (experimental legal regimes) for digital innovations in BRICS. *BRICS Law Journal*, 7(2), 10–36. https://doi.org/10.21684/2412-2343-2020-7-2-10-36

EY. (2021). EY global fintech adoption index 2021. Retrieved from https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/banking-and-capital-markets/ey-global-fintech-adoption-index.pdf [accessed on February 13th 2024]

Feng, S., Li, J., Nawi, H. M., Alhamdi, F. M., & Shamansurova, Z. (2024). Assessing the nexus between fintech, natural resources, government effectiveness, and environmental pollution in China: A QARDL study. *Resources Policy*, 88, 104433. https://doi.org/10.1016/j.resourpol.2023.104433

Ferwerda, J., Hainmueller, J., & Hazlett, C. J. (2017). Kernel-Based Regularized Least Squares in R (KRLS) and Stata (krls). *Journal of Statistical Software*, 79, 1–26. https://doi.org/10.18637/jss.v079.i03

Firdousi, S. F., Afzal, A., & Amir, B. (2023). Nexus between FinTech, renewable energy resource consumption, and carbon emissions. *Environmental Science and Pollution Research*, 30(35), 84686-84704. https://doi.org/10.1007/s11356-023-28219-z

GFN (2024).Global Footprint Network. Retrieved January 11, 2024, from https://www.footprintnetwork.org/

Gherghina, S. C., & Simionescu, L. N. (2023). Exploring the asymmetric effect of COVID-19 pandemic news on the cryptocurrency market: Evidence from nonlinear autoregressive distributed lag approach and frequency domain causality. *Financial Innovation*, 9(1), 21. https://doi.org/10.1186/s40854-022-00430-w

Global Finance Magazine. (2021). The world's most unbanked countries. Retrieved from https://www.gfmag.com/global-data/economic-data/worlds-most-unbanked-countries [accessed on February 13th 2024]

Goodkind, A. L., Jones, B. A., & Berrens, R. P. (2020). Cryptodamages: Monetary value estimates of the air pollution and human health impacts of cryptocurrency mining. *Energy Research & Social Science*, 59, 101281. https://doi.org/10.1016/j.erss.2019.101281

Guo, L., Tang, L., Cheng, X., & Li, H. (2023). Exploring the role of fintech development in reducing firm pollution discharges: Evidence from Chinese industrial firms. *Journal of Cleaner Production*, 425, 138833. https://doi.org/10.1016/j.jclepro.2023.138833

Guo, Y., Wang, F., & Li, P. (2024). The interplay of Fintech, natural resources, globalization, and environmental sustainability in China: A BARDL investigation. *Resources Policy*, 88, 104476. https://doi.org/10.1016/j.resourpol.2023.104476

Hainmueller, J., & Hazlett, C. (2014). Kernel Regularized Least Squares: Reducing Misspecification Bias with a Flexible and Interpretable Machine Learning Approach. *Political Analysis*, 22(2), 143–168. https://doi.org/10.1093/pan/mpt019

IMF. (2024). Financial Development Index Database. Retrieved January 11, 2024, from https://data.imf.org/?sk=f8032e80-b36c-43b1-ac26-493c5b1cd33b

Kartal, M. T., & Depren, O. (2023). Asymmetric relationship between global and national factors and domestic food prices: Evidence from Turkey with novel nonlinear approaches. *Financial Innovation*, 9(1), 11. https://doi.org/10.1186/s40854-022-00407-9

Kartal, M. T., Pata, U. K., Depren, O., & Erdogan, S. (2023). Effectiveness of nuclear and renewable electricity generation on CO2 emissions: Daily-based analysis for the major nuclear power generating countries. *Journal of Cleaner Production*, 426, 139121. https://doi.org/10.1016/j.jclepro.2023.139121

Koenker, R., & Bassett, G. (1978). Regression Quantiles. *Econometrica*, 46(1), 33–50. https://doi.org/10.2307/1913643

KPMG (2024) The Challenge of Greenwashing: An International Regulatory Overview, available online at chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://assets.kpmg.com/content/dam/kpmg/be/pdf/2024/ESG_Greenwashing_Report.pdf.pdf [accessed on April 7th 2025]

Lee, C. C., & Wang, F. (2022) How does digital inclusive finance affect carbon intensity?, *Economic Analysis and Policy*, Volume 75, 174-190, https://doi.org/10.1016/j.eap.2022.05.010

Lee, H. C. B., Cruz, J. M., & Shankar, R. (2018). Corporate social responsibility (CSR) issues in supply chain competition: should greenwashing be regulated?. *Decision Sciences*, 49(6), 1088–1115. https://doi.org/10.1111/deci.12307

Li, A., Li, S., Chen, S., & Sun, X. (2024). The role of Fintech, natural resources, and renewable energy consumption in Shaping environmental sustainability in China: A NARDL perspective. *Resources Policy*, 88, 104464. https://doi.org/10.1016/j.resourpol.2023.104464

Lisha, L., Mousa, S., Arnone, G., Muda, I., Huerta-Soto, R., & Shiming, Z. (2023). Natural resources, green innovation, fintech, and sustainability: A fresh insight from BRICS. *Resources Policy*, 80, 103119. https://doi.org/10.1016/j.resourpol.2022.103119

Liu, H., Chau, K. Y., Duong, N. T., & Hoang, N. K. (2024b). Fintech, financial inclusion, mineral resources and environmental quality. An economic advancement perspective from China and Vietnam. *Resources Policy*, 89, 104636. https://doi.org/10.1016/j.resourpol.2024.104636

Liu, K., Mahmoud, H. A., Liu, L., Halteh, K., Arnone, G., Shukurullaevich, N. K., & Alzoubi, H. M. (2024a). Exploring the nexus between fintech, natural resources, urbanization, and environment sustainability in China: A QARDL study. *Resources Policy*, 89, 104557. https://doi.org/10.1016/j.resourpol.2023.104557

Liu, Y. (2025). Whether fintech, natural resources, green finance and environmental tax affect CO2 emissions in China? A step towards green initiatives. *Energy*, 320, 135181. https://doi.org/10.1016/j.energy.2025.135181

Lu, Y., Tian, T., & Ge, C. (2023). Asymmetric effects of renewable energy, fintech development, natural resources, and environmental regulations on the climate change in the post-covid era. *Resources Policy*, 85, 103902. https://doi.org/10.1016/j.resourpol.2023.103902

Mertzanis, C. (2023) FinTech finance and social-environmental performance around the world, *Finance Research Letters*, Volume 56, 104107, https://doi.org/10.1016/j.frl.2023.104107

Muganyi, T., Yan, L., & Sun, H. P. (2021). Green finance, fintech and environmental protection: Evidence from China. *Environmental Science and Ecotechnology*, 7, 100107. https://doi.org/10.1016/j.ese.2021.100107

Muhammad, S., Pan, Y., Magazzino, C., Luo, Y., & Waqas, M. (2022). The fourth industrial revolution and environmental efficiency: The role of fintech industry. *Journal of Cleaner Production*, 381, 135196. https://doi.org/10.1016/j.jclepro.2022.135196

Ni, L., Yu, Y., & Wen, H. (2023) Impact of fintech and environmental regulation on green innovation: inspiration from prefecture-level cities in China. *Front. Ecol. Evol*. 11:1265531. https://doi.org/10.3389/fevo.2023.1265531

Nygaard, A., & Silkoset, R. (2023). Sustainable development and greenwashing: How blockchain technology information can empower green consumers. *Business Strategy and the Environment*, 32(6), 3801–3813. https://doi.org/10.1002/bse.3338

Okere, K. I., Dimnwobi, S. K., & Fasanya, I. O. (2025). Pathways to environmental sustainability: exploring the role of FinTech, natural resources and globalization in North Africa. *International Journal of Sustainable Development & World Ecology*, 1–19. https://doi.org/10.1080/13504509.2025.2481222

Olasehinde-Williams, G., Olanipekun, I., & Ozkan, O. (2024). Stock market response to quantitative easing: evidence from the novel rolling windows nonparametric causality-in-quantiles approach. *Computational Economics*, 64(2), 947–977. https://doi.org/10.1007/s10614-023-10450-y

Ozkan, O., Saleem, F., & Sharif, A. (2024). Evaluating the impact of technological innovation and energy efficiency on load capacity factor: empirical analysis of India. *Environmental Science and Pollution Research*, 31(4), 5610–5624. https://doi.org/10.1007/s11356-023-31233-w

Pata, U. K., Kartal, M. T., & Erdogan, S. (2024). Ecological effects of distinct patents on reducing waste-related greenhouse gas emissions in BRIC countries: Evidence from novel quantile methods. *International Journal of Sustainable Development & World Ecology*, 31(5), 554–566. https://doi.org/10.1080/13504509.2023.2301375

Pata, U. K., Usman, O., Olasehinde-Williams, G., & Ozkan, O. (2024). Stock returns, crude oil and gold prices in Turkey: evidence from rolling window-based nonparametric quantile causality test. *Asia-Pacific Financial Markets*, 31(3), 779–797. https://doi.org/10.1007/s10690-023-09430-x

Qin, L., Aziz, G., Hussan, M. W., Qadeer, A., & Sarwar, S. (2024). Empirical evidence of fintech and green environment: Using the green finance as a mediating variable. *International Review of Economics & Finance*, 89, 33–49. https://doi.org/10.1016/j.iref.2023.07.056

Qin, L., Aziz, G., Hussan, M. W., Qadeer, A., & Sarwar, S. (2024). Empirical evidence of fintech and green environment: Using the green finance as a mediating variable. *International Review of Economics & Finance*, 89, 33–49. https://doi.org/10.1016/j.iref.2023.07.056

Razzaq, A., Sharif, A., Ahmad, P., & Jermsittiparsert, K. (2021). Asymmetric role of tourism development and technology innovation on carbon dioxide emission reduction in the Chinese economy: Fresh insights from QARDL approach. *Sustainable Development*, 29(1), 176–193. https://doi.org/10.1002/sd.2139

Self, R. M., Self, D. R., & Bell-Haynes, J. (2010). Marketing tourism in the Galapagos Islands: Ecotourism or greenwashing?. *International Business & Economics Research Journal* (IBER), 9(6). https://doi.org/10.19030/iber.v9i6.590

Shahnazi, R., & Dehghan Shabani, Z.(2019) The effects of spatial spillover information and communications technology on carbon dioxide emissions in Iran. *Environ. Sci. Pollut*. Res., 26, 24198–24212. https://doi.org/10.1007/s11356-019-05636-7

Shao, Q., Wang, X., Zhou, Q., & Balogh, L. (2019) Pollution haven hypothesis revisited: A comparison of the BRICS and MINT countries based on VECM approach, *Journal of Cleaner Production*, Volume 227, 724–738, https://doi.org/10.1016/j.jclepro.2019.04.206

Silva, L. (2018) Fintech in EMEs: Blessing or curse? In Proceedings of the CV Meeting of Central Bank Governors of CEMLA, *Asunción*, Paraguay, 4–5 June.

Sim, N., & Zhou, H. (2015). Oil prices, US stock return, and the dependence between their quantiles. *Journal of Banking & Finance*, 55, 1–8. https://doi.org/10.1016/j.jbankfin.2015.01.013

Sinha, A., Mishra, S., Sharif, A., & Yarovaya, L. (2021). Does green financing help to improve environmental & social responsibility? Designing SDG framework through advanced quantile modelling. *Journal of Environmental Management*, 292, 112751. https://doi.org/10.1016/j.jenvman.2021.112751

Sinha, A., Sengupta, T., Kalugina, O., & Gulzar, M. A. (2020). Does distribution of energy innovation impact distribution of income: A quantile-based SDG modeling approach. *Technological Forecasting and Social Change*, 160, 120224. https://doi.org/10.1016/j.techfore.2020.120224

Song, Y., & Hao, Y. (2024). Understanding the relationship between Fintech, Natural Resources, Green Finance, and Environmental Sustainability in China: A BARDL approach. *Resources Policy*, 89, 104608. https://doi.org/10.1016/j.resourpol.2023.104608

Statista. (2024). B2C e-commerce sales CAGR forecast for selected countries from 2024 to 2028. Retrieved from https://www.statista.com/forecasts/220177/b2c-e-commerce-sales-cagr-forecast-for-selected-countries [accessed on February 13th 2024]

Sun, A., Bao, K., Aslam, M., Gu, X., Khan, Z., & Uktamov, K. F. (2024). Testing load capacity and environmental Kuznets curve hypothesis for China: Evidence from novel dynamic autoregressive distributed lags model. *Gondwana Research*, 129, 476–489. https://doi.org/10.1016/j.gr.2023.07.018

Sun, Y., Li, T., & Mehmood, U. (2025). Balancing acts: Assessing the roles of renewable energy, economic complexity, Fintech, green finance, green growth, and economic performance in G-20 countries amidst sustainability efforts. *Applied Energy*, 378, 124846. https://doi.org/10.1016/j.apenergy.2024.124846

Sun, Z., & Zhang, W. (2019) Do government regulations prevent greenwashing? An evolutionary game analysis of heterogeneous enterprises, *Journal of Cleaner Production*, Volume 231, 1489–1502, https://doi.org/10.1016/j.jclepro.2019.05.335

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. https://doi.org/10.1016/j.techfore.2021.121278

Tao, R., Su, C.-W., Naqvi, B., & Rizvi, S. K. A. (2022). Can FinTech development pave the way for a transition towards a low-carbon economy: A global perspective. *Technological Forecasting & Social Change*, (174), 121278. https://doi.org/10.1016/j.techfore.2021.121278

Udeagha, M. C., & Ngepah, N. (2023). The drivers of environmental sustainability in BRICS economies: do green finance and fintech matter?. *World Development Sustainability*, 3, 100096. https://doi.org/10.1016/j.wds.2023.100096

Udeagha, M. C., & Breitenbach, M. C. (2023a) Exploring the moderating role of financial development in environmental Kuznets curve for South Africa: fresh evidence from the novel dynamic ARDL simulations approach. *Financ Innov* 9, 5 (2023). https://doi.org/10.1186/s40854-022-00396-9

Udeagha, M. C., & Breitenbach, M. C. (2023b) Revisiting the nexus between fiscal decentralization and CO2 emissions in South Africa: fresh policy insights. *Financ Innov* 9, 50 (2023). https://doi.org/10.1186/s40854-023-00453-x

UNFCCC (2023). United Nations Framework Convention on Climate Change. Summary of Global Climate Action at COP 28. https://unfccc.int/documents . [Accessed:01.02.2024]

Usman, O., Iorember, P. T., Ozkan, O., & Alola, A. A. (2024). Dampening energy security-related uncertainties in the United States: The role of green energy-technology investment and operation of transnational corporations. *Energy*, 289, 130006. https://doi.org/10.1016/j.energy.2023.130006

Wang, X., Wang, X., Ren, X., & Wen, F. (2022) Can digital financial inclusion affect CO2 emissions of China at the prefecture level? Evidence from a spatial econometric approach, *Energy Economics*, Volume 109, 105966, https://doi.org/10.1016/j.eneco.2022.105966

Wang, Z., Fu, H., & Ren, X. (2023a). Political connections and corporate carbon emission: New evidence from Chinese industrial firms. *Technological Forecasting and Social Change*, 188, 122326. https://doi.org/10.1016/j.techfore.2023.122326

Wang, L., Fan, X., Zhuang, H., Liu, A., Wu, Z., Wang, Q., et al. (2023b). ESG disclosure facilitator: How do the multiple large shareholders affect firms' ESG disclosure? Evidence from China. *Frontiers in Environmental Science*, 11, 83–100. https://doi.org/10.3389/fenvs.2023.1063501

Wei, H., Yue, G., & Khan, N. U. (2024). Uncovering the impact of Fintech, Natural Resources, Green Finance and Green Growth on Environment sustainability in BRICS: An MMQR analysis. *Resources Policy*, 89, 104515. https://doi.org/10.1016/j.resourpol.2023.104515

Wei, H., Yue, G., & Khan, N.U. (2024) Uncovering the impact of Fintech, Natural Resources, Green Finance and Green Growth on Environment sustainability in BRICS: An MMQR analysis, *Resources Policy*, Volume 89, 104515, https://doi.org/10.1016/j.resourpol.2023.104515

World Bank. (2021). Individuals using the internet (% of population). Retrieved from https://data.worldbank.org/indicator/IT.NET.USER.ZS [accessed on February 13th 2024]

Xia, A., & Liu, Q. (2024). Modelling the asymmetric impact of fintech, natural resources, and environmental regulations on ecological footprint in G7 countries. *Resources Policy*, 89, 104552. https://doi.org/10.1016/j. resourpol.2023.104552

Xie, J., Chen, L., Liu, Y., & Wang, S. (2023). Does fintech inhibit corporate greenwashing behavior?-Evidence from China. *Finance Research Letters*, 55, 104002. https://doi.org/10.1016/j.frl.2023.104002

Xu Q., & Kim T. (2022). Financial constraints and corporate environmental policies. Rev. *Financial Stud*. 35 (2), 576–635. https://doi.org/10.1093/rfs/hhab056

Xue, Q., Feng, S., Chen, K., & Li, M. (2022). Impact of digital finance on regional carbon emissions: An empirical study of sustainable development in China. *Sustainability*, 14(14), 8340. https://doi.org/10.3390/su14148340

Yang, H., Zou, J., Luo, Y., Wang, Y., Qiu, Y., & Guo, H. (2024). The role of fintech, natural resources, and energy use in shaping environmental sustainability in China: A QARDL perspective. *Resources Policy*, 89, 104650. https://doi.org/10.1016/j.resourpol.2024.104650

Yang, M., She, D., Abbas, S., Ai, F., & Adebayo, T. S. (2023a). Environmental cost of financial development within the framework of the load capacity curve hypothesis in the BRICS economies: Do renewable energy consumption and natural resources mitigate some burden? *Geological Journal*, 58(10), 3915–3927. https://doi.org/10.1002/gj.4817

Yang, Y., Xu, G., & Li, R. (2023b). Official turnover and corporate ESG practices: Evidence from China. *Environ. Sci. Pollut. R.* 30 (18), 51422–51439. https://doi.org/10.1007/s11356-023-25828-6

Zahid, R. A., Khan, M. K., Anwar, W., & Maqsood, U. S. (2022). The role of audit quality in the ESG-corporate financial performance nexus: Empirical evidence from Western European companies. *Borsa Istanbul Review*, 22, S200-S212. https://doi.org/10.1016/j.bir.2022.08.011

Zhang, D., & Liu, L. (2022). Does ESG performance enhance financial flexibility? Evidence from China. *Sustainability* 14 (8), 11324. https://doi.org/10.3390/su141811324

Zhou, G., Zhu, J., & Luo, S. (2022). The impact of FinTech innovation on green growth in China: Mediating effect of green finance. *Ecological Economics*, (193), 107308. https://doi.org/10.1016/j.ecolecon.2021.107308

Authors' Biographies

Oktay Ozkan is an Associate Professor of Finance at the Faculty of Economics and Administrative Sciences, Tokat Gaziosmanpasa University, Turkey. He ranked 624th among approximately 1.5 million candidates in the university entrance exam held by the Republic of Turkey Measurement, Selection and Placement Center in 2006. He graduated from TOBB University of Economics & Technology, Ankara/Turkey. He was awarded the Scientific and Technological Research Council of Turkey (TÜBİTAK) scholarship, a prestigious accolade granted to very few individuals in Turkey, for both his master's and Ph.D. studies. He earned his Ph.D. degree in 2020 from Tokat Gaziosmanpasa University, Turkey. His research has been published in several reputable international journals, such as Energy Economics, Journal of Cleaner Production, Energy, Journal of Environmental Management, Resources Policy, and Research in International Business and Finance. His areas of expertise and research interest include financial markets and institutions, financial forecasting and modeling, investments and portfolio management, applied econometrics, energy and environmental economics, and applied time-series econometrics.

Magdalena Radulescu received her B.A. and M.A. in Finance, as well as her Ph.D. and Habilitation for Ph.D. Supervision in Economics, from the Academy of Economic Studies, Bucharest, Romania. She is a Full Professor in the Department of Finance, Accounting and Economics, Faculty of Economic Studies, National University of Science and Technology Politehnica Bucharest, Romania. She also serves as a Ph.D. Supervisor in Economics at the University "Lucian Blaga" of Sibiu, Romania. She is an Associate Editor of Environment, Development and Sustainability (Springer) and Geological Journal (Wiley), and acts as Guest Editor for numerous international journals, including Journal of Risk and Financial Management, Frontiers in Environmental Sciences, Frontiers in Energy Research, Environmental Science and Pollution Research, Environmental Research Communication, Utilities Policy, Environment, Development and Sustainability, Journal of Urban Technology, Resources Policy, etc. She has been recognized among the top 2% of the world's most influential scientists for 2024, as listed by Stanford University.

Mehmet Akif Destek is an Associate Professor of Economics at the Faculty of Economics and Administrative Sciences, Gaziantep University, Turkey. His research interests include energy economics, environmental economics, and applied economics. He has published in some leading Web of Science–indexed journals, such as Energy, Renewable Energy, Journal of Cleaner Production, Resources Policy, Sustainable Development, Science of the Total Environment, and Technological Forecasting and Social Change. The researcher has been listed among the top 2% of the world's most influential scientists for 2021, 2022, 2023, and 2024 by Stanford University, and according to the RePEc platform, he ranks among the best young economists in the world in 2024.

Madalina Brutu is Associate Professor at the National University of Science and Technology Politehnica Bucharest, Romania. She graduated from the Management Faculty at the University Constantin Brancoveanu Pitesti and earned her PhD from the Academy of Economic Studies, Bucharest, Romania. Her expertise is in organizational management.

The article has been reviewed.
Received in January 2025; accepted in September 2025.