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# Environmental Impact of Digital Financial Inclusion and Green Growth: Insights from Global Panel Data Analysis

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## Abstract

This paper analyzes the environmental effects of digital financial inclusion (DFI) along with green growth using panel data from 102 economies over the period 1990-2022. The analysis used mobile cellular subscriptions (MCSs), bank branches (BB), and automated teller machines (ATMs) as proxy variables of DFI. The empirical results are estimated employing Pooled Ordinary Least Square (POLS) and Method of Moments Quantile Regression (MMQR) estimation approaches. The findings suggest that an increase in DFI reduces environmental quality. Intriguingly, a comparative assessment of DFI measures indicates that while an increase in MCSs is associated with an enhancement of environmental quality, the proliferation of BB and ATMs tends to diminish it. The analysis shows that green economic growth leads to lower emissions. The environmentally improving effect of green growth remains robust across all quantiles. The analysis also validates the Pollution Halo Hypothesis, shedding light on the point where expanding economies begin to curtail environmental degradation. Altogether, this study enhances the literature by conducting a comprehensive analysis of the interplay between DFI, green growth, and environmental quality, offering valuable insights for policy formulation in the contemporary digitally driven and environmentally aware global landscape.

**Keywords:** CO2 emissions, financial inclusion, ATMs, mobile cellular subscriptions, bank branches, urbanization, energy use, digital financial inclusion index.

## 1. Introduction

Environmental quality is a fundamental pillar that shapes the quality of life, the health of ecosystems, and the stability of the natural world. It influences the overall well-being and sustainability of our planet. In recent years, a consensus has emerged among researchers, energy scientists, environmentalists, and sustainable development experts that environmental changes have significant adverse effects on human health and quality of life, including loss of natural habitats for future generations (Tahir et al. 2020; United Nations Environment Programme, 2019). Many worldwide challenges such as deforestation, soil erosion, melting glaciers, rising sea levels, droughts, and floods are largely attributed to climate change (Majeed & Mazhar 2019a). These outcomes pose threats to human lives, infrastructure, natural capital, and agrarian lands. The contemporary ecological losses have inspired global organizations and policymakers to highlight the pressing need to mitigate greenhouse gas (GHG) emissions to preserve environmental quality.

To preserve environmental quality, certain global environmental regulations and efforts have been initiated. The Kyoto Protocol- signed in 1997 and executed in 2005- has declared that GHG emissions need to be reduced in certain boundaries. Likewise, the United Nations (UN) has considered clean energy as the seventeenth sustainable development goal to discourage GHG emissions. The IPCC (2018) has asserted that GHG emissions need a reduction of 45 percent by 2030 than that of 2010 levels, to attain the goal of net-zero emissions by 2050 and to attain the goal of 1.5 °C. Ecological quality is generally associated with economic activities, particularly when economic activities prioritize growth at the cost of the environment.

Considering the contemporary climatic challenges, this research study focuses on novel factors of environmental changes such as digital financial inclusion (DFI) and green growth prospects. The World Bank (2022) describes financial inclusion as "the process where individuals and businesses have access to useful and affordable financial products and services that meet their needs like transactions, payments, savings, credit, and insurance". Now, digital financial services are increasing all over the world. For instance, mobile phone subscriptions have been provided all over the world, and "millions of previously excluded and underserved poor customers are transitioning from cash-based transactions to formal financial services via mobile phones or other digital technology" (Mhlanga, 2020; World Bank, 2022). This DFI is associated with environmental quality.

The literature has highlighted the multifaceted nature of the association between DFI and environmental loss and its importance for sustainable development. The rise of digital finance and mobile banking is noted for its potential to reduce paper usage, thereby contributing to environmental preservation. However, the literature also suggests contrasting effects, wherein higher financial inclusion might lead to increased consumption and environmental pollution due to the acquisition of resource-intensive goods. The extant empirical studies have largely explored financial development and environmental quality nexus overlooking the importance of DFI.

Recently, some studies provided country-specific or regional-specific evidence on the DFI-environment nexus. However, the findings of these studies cannot be generalized in a global economy. Besides, the extant studies do not show a clear relationship between DFI and environmental quality. The studies such as Liu et al. (2022c) for the economy of China, Du et al. (2022) for emerging developing countries, Zaidi et al. (2021) for OECD countries, and Tufail et al. (2022) for the BRICS economies suggest a favorable role of FDI for environmental preservation. According to these studies, a surge in DFI improves the environment by improving access to financial resources which can be used to reduce environmental effects. For instance, DFI helps the poor, small agriculture landholders, and small businesses to invest in clean energy (Majeed & Mazhar, 2019b).

Contrary to this, Frankel and Romer (1999) predicted that availability and access to financial resources encourage consumers to buy conventional energy-intensive products like vehicles, refrigerators, and air conditions which significantly contribute to escalating GHG emissions. Ding et al. (2022) provide heterogeneous effects of DFI on CO2 emissions in China using provincial-level data. Likewise, Alwi (2021) suggested that an increase in DFI is associated with buying personal mobile devices like smartphones which facilitate mobile banking and enhance the flexibility of buying consumer goods. Meanwhile, the importance of green growth has also inspired the interest of research scholars and policymakers. For example, the shift toward green growth aligns with the Environmental Kuznets Curve (EKC) theory. According to this theory, in the early stages of economic development, environmental degradation tends to increase, but once a certain income level is reached, economies tend to prioritize green growth, leading to greater sustainability. However, the lack of a unified framework and clear consensus on the mechanisms and conditions that drive the green growth and environmental quality nexus calls for further investigation.

Against this milieu, the present research makes several noteworthy contributions to the contemporary literature in the field of DFI, green growth, and environmental quality. To our knowledge, no past study has investigated the comparative effects of DFI on carbon emissions in the context of the global economy. By incorporating three different measures of DFI—mobile subscriptions, commercial banks, and the number of ATMs—the study provides more holistic insights into the association between DFI and environmental quality. Moreover, this study also constructs a composite index to provide a more compact picture of the association between DFI and environmental quality.

The inclusion of green growth as a focus of investigation alongside DFI enhances its relevance to current sustainability challenges. By examining the DFI, green growth, and environmental quality, the study addresses a critical gap in the literature and offers insights into how DFI can be aligned with environmental goals. The study contributes methodologically by using the novel method of moments quantile regression (MMQR) approach. This technique offers a nuanced analysis of the distributional effects, allowing for a deeper understanding of how DFI's impact on environmental quality might vary across different levels of carbon emissions. Policymakers can use the study's findings to design strategies that promote both DFI and green growth, while also considering potential trade-offs and variations across different segments of the population.

The remaining paper is structured as follows. Section 2 discusses the literature. Section 3 explains the "model, data, and methodology". Section 4 provides a discussion on empirical outcomes. Lastly, Section 5 concludes the paper.

## 2. Literature Review

The literature on digital financial inclusion, green growth, and environmental quality has attracted the attention of environmental economists, energy experts, and financial managers. This section is divided into three sub-sections to discuss the relevant literature. Section 2.1 focuses on the theory and empirics of digital financial inclusion and environmental quality. Section 2.2 presents literature on green growth and environmental quality nexus. The last section 2.3 summarizes the discussion and highlights the research gaps and contribution of the present study.

### *2.1 Digital Financial Inclusion and Environmental Quality*

Financial development and financial inclusion have emerged the important predictors of economic growth and stability. It accelerates economic growth by facilitating the efficient allocation of savings, and stimulating innovation and entrepreneurship (Levine, 2001). It increases investor confidence by offering risk management tools such as insurance products, derivatives, and different hedging instruments (Ghirmay, 2004). With this along with FI, DFI is gaining importance in the recent arena. DFI is the development that ensures that everyone in a community, irrespective of their socioeconomic position or geographical location, can have access to digital financial services and can use technology efficiently. It goes beyond mere access to banking services and in turn influences environmental quality through various paths (Ali et al., 2023).

The relationship between DFI and environmental quality can be well explained with the insights provided by the theory of sustainable development. It is a holistic framework that development should not come at the expense of future generations, emphasizing a balance between economic prosperity, social equity, and environmental stewardship. These three interconnected dimensions, often referred to as the "triple bottom line," recognize the need for responsible economic growth, improved quality of life for all members of society, and environmental protection. It is relevant both locally and globally, involving participation, policy implementation, technology, and measurement, improving environmental quality. Additionally, according to Berg et al. (2022), DFI can facilitate access to renewable energy solutions by providing people and communities with affordable financing choices. This decreases dependency on traditional fossil fuels. It can also make it easier for small-scale farmers to invest in sustainable agricultural practices, leading to higher yields and reduced environmental degradation. Microfinance and mobile banking services can help farmers access credit for purchasing eco-friendly inputs (Karlan & Zinman, 2009).

Green microfinance focuses on funding projects that have positive environmental impacts, such as sustainable agriculture, renewable energy, and waste management (Attigah et al., 2015). The rise of digital finance and mobile banking can contribute to reduced paper usage, as electronic transactions and digital records replace traditional paper-based methods. This can lead to lower deforestation rates and decreased demand for paper products (Mas & Redcliffe, 2011). In contrast, higher financial inclusion increased consumption such as refrigerators, iron, automobiles, microwaves, washing machines, air-conditioners, and dishwashers, resulting in more resource depletion and increased environmental pollution emissions (Hoddy & Kletzer, 2018).

The empirical literature is broad, focusing on different times and countries. Focusing on financial inclusion Le et al. (2020) for the Asian economies, Renzhi & Baek (2020) for the panel of 103 countries, Mehmood (2022) for South Asian countries, Liu et al. (2022a) for emerging Asian countries, Ahmad et al. (2022) for BRICS economies, and Dou & Li (2022) for BRICS countries have explored that FI has a negative influence on the environmental quality. While a beneficial impact of FI concerning the environment is validated by Liu et al. (2022c) for the economy of China, Du et al. (2022) for emerging economies, Zaidi et al. (2021) for the sample of OECD countries, Ullah et al. (2022) for OECD countries, Shabir (2022) for Asia–Pacific Economic Cooperation (APEC) nations, and Tufail et al. (2022) for the BRICS economies.

Recent literature has been notably centered on exploring the association between DFI and environmental quality. Ding et al. (2022) for the 30 Chinese provinces, Lee et al. (2022) for the 277 Chinese cities, and Liu et al. (2022b) for E7 economies have concluded that DFI can add to carbon-lessening capability. In a similar context, Mhlanga (2022) DFI can help households, individuals, and businesses be more flexible in the setting of a fast climatic disaster or the gradual consequences of shifting rainfall patterns and in turn reduce the environmental-related risks. Within the context of the One Belt and Road Initiative (OBRI) region Ozturk & Ullah (2022), tackles the complex challenges of promoting DFI, economic growth, and environmental quality. Analyzing data spanning 42 OBRI countries from 2007 to 2019, the research employs OLS, 2SLS, and generalized method of moments (GMM) techniques. The empirical results underscore that while DFI contributes to economic growth, it also correlates with reduced environmental quality due to increased CO2 emissions.

Salman and Ismael (2023) assessed the influence of DFI on green growth in Egypt using the extended STIRPAT model, deducing that DFI contributes to long-term carbon emission limitation. Ali et al. (2023) explored the influence of DFI, energy transition, and diversification on attaining the objectives of the United Nations Sustainable Development Goals (SDGs) and the Climate Change Conference (COP26) targets within the framework of emerging seven economies (E-7). The authors have employed various econometric techniques such as panel quantile regression, ordinary least squares, and mean group causality tests. Their result verifies the environmental worsening impact of DFI. Chang et al. (2023) examined the co-movement between financial inclusion and sustainable energy performance indices in light of COVID-19 consequences. Findings highlight China's leading energy performance among E7 economies, followed by Russia. Indonesia and Turkey show promising sustainability prospects, while Mexico and Brazil exhibit lower scores.

Cheng et al. (2023) by utilizing the Malmquist-Luenberger index to assess Green Total Factor Productivity (GTFP) across 276 Chinese cities from 2011 to 2019, investigated the DFI's influence on GTFP through "innovation and entrepreneurship lenses". The findings show that DFI fosters GTFP growth by propelling green innovation and entrepreneurial endeavors at the micro level. The results also indicate DFI's promotion impact on GTFP is particularly pronounced in the eastern region and non-resource-based cities. Chinoda and Kapingura (2023) direct their attention to Sub-Saharan Africa's economy. By compiling data spanning from 2014 to 2020, their findings indicate that DFI exerts a dual influence as stimulating economic growth while simultaneously contributing to environmental sustainability.

Xin et al. (2023) utilize panel data encompassing 281 Chinese cities spanning from 2011 to 2020. Employing the Entropy-TOPSIS and DEA methodologies, this research establishes a substantial association between DFI and the promotion of green growth. Their analysis highlights that innovations and industrial upgrading stand as the primary drivers of this relationship. Heterogeneity analysis underscores the significance of the digital economy's role in fostering inclusive green growth, particularly evident in eastern region cities, larger urban locales, and cities marked by elevated marketization. Then, in a very recent study, Zheng et al. (2023) utilized the 2SLS, GMM approaches, and panel quantile regression. They conclude that DFI and COVID-19 both have a negative influence on carbon emissions.

*2.2 Green Growth and Environmental Quality*

Green growth, as a strategy for sustainable economic development, aims to balance economic prosperity with environmental protection. Its impact on environmental quality and pollutant emissions is a topic of active research, with studies investigating how adopting green growth principles can influence pollutant emissions. The theoretical linkage between green growth and its impact on carbon emissions can be explained through the lens of the EKC proposed by Grossman and Krueger (1995). The EKC hypothesis suggests that as economies initially grow, environmental degradation tends to increase due to higher industrialization and energy consumption. However, beyond a certain income threshold, further economic growth can lead to increased awareness, technological advancements, and the adoption of cleaner technologies. This transition promotes a decline in CO2 emissions despite continued economic expansion, ultimately resulting in a downward-sloping curve. This implies that by achieving a threshold level of economic development, societies tend to experience a shift towards "green growth," where economic growth and technological advancement coincide with improved environmental quality and sustainability.

Additionally, green growth emphasizes resource efficiency and the transition to a circular economy, where products are designed for durability, repairability, and recycling. By minimizing waste generation and promoting the reuse of materials, less energy is needed for the production of new goods, leading to reduced CO2 emissions associated with manufacturing. This growth also encourages the diversification of economies into sectors that have lower environmental impacts. This can include investments in clean energy industries, sustainable agriculture, and eco-tourism. As these sectors expand, they contribute to economic growth while emitting fewer CO2 emissions compared to traditional sectors (Zhang et al., 2020). Green growth can also affect environmental quality according to the energy economy theory. This theory examines the allocation of resources, acknowledging the potential for clean energy transitions to encourage technological innovation and job creation. It emphasizes the role of government policies and regulations in shaping energy markets and driving clean energy adoption. This theory plays a crucial role in understanding the energy transition, the role of renewable energy sources, and the optimization of energy systems for economic and environmental benefits.

In the empirical settings, few studies have taken green growth as a determinant of carbon emissions. Sonnenschein & and Mundaca (2016) in this respect provide an empirical analysis of the South Korean economy. By taking the data from 2008 to 2012 and utilizing the decomposition analysis their results reveal that the green growth strategy remains effective in decarbonizing the economy. Hao et al. (2021) by focusing on G7 countries and taking the data from 1991 to 2017 employs the cross-sectionally augmented auto-regressive distributive lag (CS-ARDL) model. Their results highlight that both linear and non-linear green growth terms contribute to CO2 emission reduction. Chein et al. (2021) by using the quantile ARDL provide a similar conclusion for the economy of the United States of America (USA).

Saleem et al. (2022) investigated the influence of green growth on the environment for 12 Asian economies from 1990 to 2018. Applying the CS-ARDL method, the study explores the relationship between green growth, GDP growth, and environmental quality, considering plausible variables within the context of the EKC. The findings reveal that carbon emissions are influenced by green growth and technological progression in Asian countries. While an inverted U-shaped EKC is evident for GDP, a concave EKC pattern emerges for green growth. Dong et al. (2022) for the economy of China, Maiti (2022) for the panel of 32 countries, and Yu et al. (2023) for the Chines economy find similar results. Wei et al. (2023) focus on the top "green future economies" and consider the period from 1990 to 2018. They utilize the CS-ARDL method. For the robustness check, they used augmented mean group (AMG) and common correlated effect mean group (CCEMG) methods. The results of their analysis revealed that factors related to green competitiveness and green trade play a pivotal role in reducing carbon emissions, subsequently improving the quality of the environment.

Deng et al. (2023) on the other hand took the data of highly polluted economies covering the period from 1991 to 2019. For empirical examination, they utilize the ARDL bounds testing approach. Their result proves that an efficient financial system is connected with green growth that promotes sustainability. Zhao et al. (2023) considered the association between green growth and CO2 in the Chinese economy. They apply the OLS and feasible generalized least squares (FGLS) technique for the empirical analysis. Their findings indicate that green growth facilitates a reduction in carbon emissions. Xi and Wang (2023), Mukalayi & Inglesi-Lotz (2023), and Schilling & Seuring (2023) also find similar results.

*2.3 Summary, Research Gap, and Contribution*

The literature review presents a comprehensive overview of the relationship between DFI, green growth, and environmental quality. The authors highlight the multifaceted nature of this relationship between DFI and environmental quality and its implications for sustainable development. According to the literature, the rise of digital finance and mobile banking is noted for its potential to reduce paper usage, thereby contributing to environmental preservation. However, contrasting effects are also observed. Similarly, regarding green growth and environmental quality relationship, the literature mainly documents the beneficial role of green growth in managing environmental quality. However, there remains a research gap in comprehensively understanding the multifaceted relationships among these factors, especially in various country contexts. While some studies identify positive effects, others highlight negative consequences. The lack of a unified framework and clear consensus on the mechanisms and conditions that drive these relationships calls for further investigation.

The study indeed makes several noteworthy contributions to the existing literature in the field of DFI, green growth, and environmental quality. These contributions are as follows: By incorporating three different measures of DFI—mobile subscriptions, commercial banks, and the number of ATMs—the study offers a more holistic understanding of the relationship between DFI and environmental quality. This multi-dimensional approach enhances the robustness of the analysis and captures the diverse impact of various aspects of DFI on environmental outcomes. Then investigating the relationship between DFI and environmental quality using both individual DFI measures and a composite index is a valuable contribution. This approach allows for the identification of the unique impact of each DFI measure while also providing insight into their combined effect on environmental quality.

The inclusion of green growth as a focus of investigation alongside DFI enhances its relevance to current sustainability challenges. By examining the DFI, green growth, and environmental quality, the study addresses a critical gap in the literature and offers insights into how financial inclusion can be aligned with environmental goals. The study contributes methodologically by employing the MMQR approach. This technique offers a nuanced analysis of the distributional effects, allowing for a deeper understanding of how DFI impacts on environmental quality might vary across different levels of distribution. Through its comprehensive analysis and methodological advancements, the study provides insights that can inform policy decisions aimed at fostering sustainable development. Policymakers can use the study's findings to design strategies that promote both DFI and green growth, while also considering potential trade-offs and variations across different segments of the population.

## 3. Data and Model Specification

### *3.1 Data*

This research evaluates the environmental impact of DFI and green growth on CO2 emissions. The research exploits the panel data on specified variables from multiple data sources. More specifically, the data on response variable environmental degradation is gathered from the World Bank (2023). Whereas the data on the green growth variable is extracted from the Organization for Economic Cooperation and Development (2023). In this research, the proxy variables of DFI are gathered from different sources for instance: data showing branches of commercial banks and automated teller machines (ATMs) is taken from the statistics of International Monetary Funds (2023) while data on mobile cellular subscription is compiled from World Bank (2023). Likewise, data on all control variables is retrieved from the World Bank (2023). Comprehensive analysis is done on panel data of 102 countries with a time frame of 1990-2022. The country list is provided in Appendix A1.

### *3.2 Model Specification*

#### 3.2.1 Theoretical Framework

Generally, the analysis to detect the impact of human activities on environmental quality is based on the conceptual framework of the IPAT model. This study uses an extended version of this framework named as STIRPAT model. The model, proposed by Ehrlich & Holdren (1971), significantly determines the driving factors of environmental quality and is written as:

$$\boldsymbol{I = aP^{b}A^{c}T^{d}} \in$$

The model can be written in linear regression form as:

$$\boldsymbol{lnI = ln\,a + b\,ln\,P + c\,ln\,A + d\,ln\,T + f\,ln\,E + ln} \in \qquad (1)$$

Whereas, I show the proxy representing environmental quality, which stands for the constant term and ∈ reflects the error term. P, A, and T are population variables, affluence, and technology variables determining environmental aspects. Similarly, b, c, and d are the elements of attached variables P, A, and T respectively. T in the regression equation captures the contribution of additional variables in driving environmental quality. Based on this theoretical framework, the current research computes the role of DFI and green growth on the environment by controlling factors of population, trade, energy usage, technological advancement, and foreign direct investments.

### 3.2.2 Econometric Modelling

Based on the objectives of the current study, the STIRPAT regression model mentioned in Equation 1 can be extended into the following form:

$$\boldsymbol{EnvD_{it} = \alpha_1 + \alpha_2 GRG_{it} + \alpha_3 DFI_{it} + \alpha_4 URB_{it} + \alpha_5 TR_{it} + \alpha_6 EnU_{it} + \alpha_7 TEC_{it} + \alpha_8 FDI_{it}} + \varepsilon_{\boldsymbol{it}} \qquad (2)$$

Where the subscript "i" reflects 102 countries and "t" shows years ranging from 1990 to 2022. α_1 is an intercept term in the equation whereas α_2 to α_8 shows the coefficients of respective variables and the error term is shown by ε_it. EnvD representing environmental degradation is the response variable and is proxied by carbon dioxide emissions. As per the description by the World Bank, (2023), this variable represents "the emissions stemming from the burning of fossil fuels and the manufacture of cement along with the carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring". It is measured in metric tons per capita. GRG in equation 2 refers to green growth. The current study uses the proxy variable of "environmental and resource productivity". It measures the production-based carbon dioxide productivity of an economy.

This study utilizes three proxy variables as a measure of digital financial inclusion abbreviated as DFI to capture its comprehensive dimensions. Firstly, mobile cellular subscriptions are used as the first proxy variable of DFI. This indicator shows "subscriptions to a public mobile telephone service that provide access to the PSTN using cellular technology and includes (and is split into) the number of postpaid subscriptions, and the number of active prepaid accounts (i.e., that have been used during the last three months)" (World Bank, 2023). The second proxy variable used for DFI in the current study is the number of commercial bank branches in the state whereas the third measuring variable of DFI in the study includes the number of Automated Teller Machines (ATMs) in an economy. The study utilizes these measures separately in the model while their index is also utilized which is generated with the help of principal component analysis.

URB in equation 2 shows the variable of population, which is captured by the proxy variable of urban population as a percentage of the total population. Likewise, TR in percentage of GDP shows the trade variable which is the sum of exports and imports of a country. The variable EnU reflects the energy usage variable, which is measured in kilograms of oil per capita. Technology (TEC) in current work is proxied through the "number of residents' patent applications". Lastly, foreign direct investment mentioned as FDI in equation 2 is also controlled in the current study. It measures the net inflow of investments in an economy as a percentage of GDP.

### 3.2.3 Econometric Technique

A formulated regression model expressed in equation 2 is computed with the help of a baseline technique pooled ordinary least square (OLS) estimator. After the baseline approach, the study exploits an advanced and extended approach to quantile regression introduced by Machado & Silva (2019) named "Method of Moments Quantile Regression (MMQR)". The quantile regression computes more reliable outcomes in the presence of outliers. This approach is more appropriate for tracing heterogeneous distribution variations across all quantiles between environmental degradation variables and its observed regressors in selected panel datasets. The equation representing the condition quantile can be expressed as:

$$Y_{it} = \alpha_i + X'_{it}\,\beta + (\delta_i + Z'_{it}\,\emptyset)U_{it} \quad \text{(3a)}$$

This equation 3a implies that:

$$Q_Y\,(\tau \mid X_{it}) = \left(\alpha_i + \delta_i q\,(\tau)\right) + X'_{it}\,\beta + Z'_{it}\,\emptyset q(\tau) \qquad (3b)$$

In the context of the current analysis, equation 3b can be documented as:

$$Q_{EnvD}\,(\tau \mid X_{it}) = \left(\alpha_i + \delta_i q\,(\tau)\right) + X'_{it}\,\beta + Z'_{it}\,\emptyset q(\tau) \qquad (3b)$$

Where, $Q_{EnvD}\,(\tau \mid X_{it})$ represents the quantile distribution of environmental degradation. $X_{it}$ reflects the vector of all regressors including DFI, green growth, population, trade, energy usage, technological advancement, and foreign direct investments. Whereas $q(\tau)$ expresses the quantiles (τth) of the sample set which is computed with the optimization of the following problem set:

$$min_q \Sigma_i\, \Sigma_t \varphi_t(R_{it} - (\delta_i + Z'_{it}\,\emptyset)q) \quad (3c)$$

Based on the MMQR approach, the final model of the present study can be constructed as follows:

**Model 1:** $\mathbf{QEnvD_{it}\,(\tau_k \mid \alpha_i X_{it}) = \alpha_i + \emptyset_2 GRG_{it} + \emptyset_3 DFII_{it} + \emptyset_4 URB_{it} + \emptyset_5 TR_{it} + \emptyset_6 EnU_{it} + \emptyset_7 TEC_{it} + \emptyset_8 FDI_{it} + \varepsilon_{it} \qquad (4)}$

Whereas, the FDII represents the index of digital financial inclusion. The second model is also estimated with the inclusion of three proxies of DFI separately as mentioned below:

**Model 2:** $\mathbf{QEnvD_{it}\,(\tau_k \mid \alpha_i X_{it}) = \alpha_i + \emptyset_2 URB_{it} + \emptyset_3 DFI1_{it} + \emptyset_4 DFI2_{it} + \emptyset_5 DFI3_{it} + \emptyset_6 EGR_{it} + \emptyset_7 TR_{it} + \emptyset_8 EnU_{it} + \emptyset_9 TEC_{it} + \emptyset_{10} FDI_{it} + \varepsilon_{it} \qquad (5)}$

Thus, the study estimates models 1 and 2 by exploiting the MMQR approach. This estimator provides relevantly robust outcomes in the presence of non-normality, non-linearity, and endogeneity issues in sample sets (Awan et al., 2022; Jahangir et al., 2023). To check the suitability of MMQR, the distribution of the response variable is checked by constructing a kernel density histogram. Additionally, a "Quantile-Quantile" plot is also constructed to track the normality of environmental degradation in a panel set.

## 4. Results and Discussion

### *4.1. Carbon Emissions: Distribution Across the Globe*

Figure 1 shows the map depicting carbon emissions at the global level with varying shades of royal blue, Egyptian blue, and light blue colors can provide valuable insights into the distribution of carbon dioxide emissions across different regions of the world. The color scheme conveys information about the relative levels of carbon emissions in various geographical areas. Royal blue areas on the map indicate regions with lower carbon emissions. These areas may have relatively lower industrialization, a focus on renewable energy sources, or effective environmental policies in place that have resulted in reduced carbon output. Egyptian shades of blue represent regions with moderate carbon emissions. These areas may still contribute significantly to global carbon emissions but might have implemented certain measures to control emissions or have a less-intensive industrial presence compared to the high blue areas. Lighter shades of blue on the map would indicate regions with the highest levels of carbon emissions. These areas are likely to be significant contributors to global carbon dioxide output, possibly due to industrialization, urbanization, and other factors that lead to increased fossil fuel consumption.

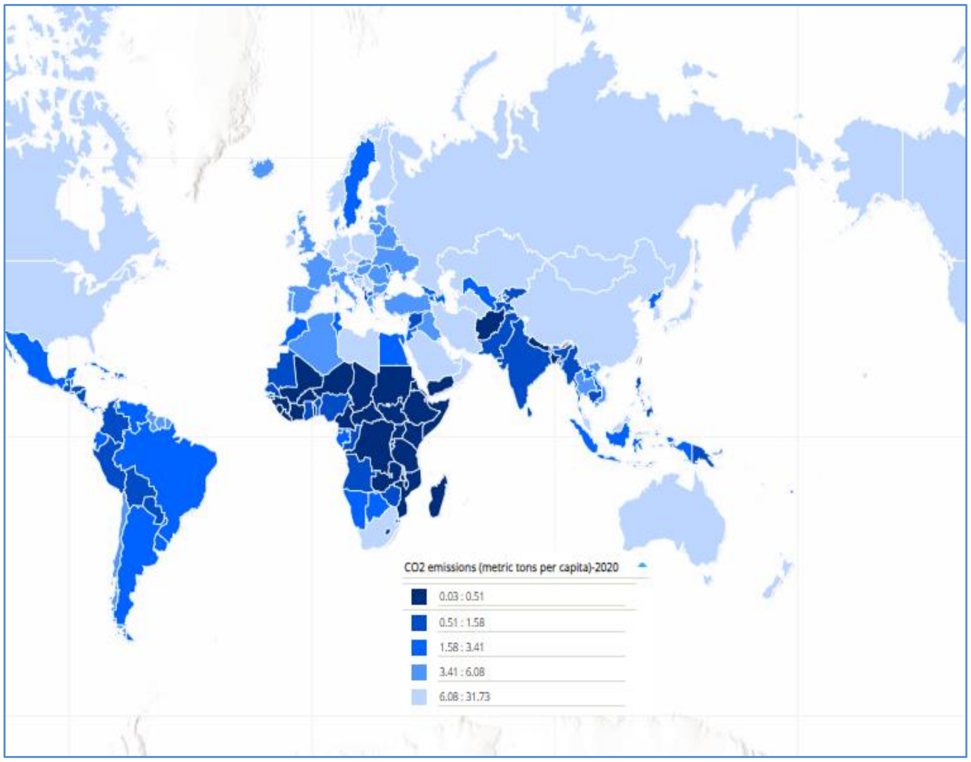


**Figure 1: Map Illustrating the Environmental Degradation at the Global Level**
(Source: World Bank, 2023)

*4.2. Descriptive Statistics*

Descriptive statistics play a crucial role in the initial exploration of a dataset. Table 1 shows the descriptive statistics for study variables in the dataset. These statistics offer magnitudes of mean values, standard deviation, and range of the data. For instance, looking at the variable EnvD, with 3162 observations, the average environmental degradation score is approximately 5.575, with a standard deviation of around 5.919. The lowest degradation score observed is 0.025, while the highest is 47.657. Similarly, for GRG (Green Growth), based on 3137 observations, the mean is roughly 5.475, and the standard deviation is about 3.842, indicating variability in the extent of green growth across observations. DFII (Digital Financial Inclusion Index) spans 1699 observations with a maximum value of 3.103 and a minimum of -3.318. These statistics help in understanding the distribution of the variables, highlighting their variability and potential trends.

**Table 1: Descriptive Statistics**

| Variables | Obs. | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| **EnvD** | 3162 | 5.575 | 5.919 | .025 | 47.657 |
| **GRG** | 3137 | 5.475 | 3.842 | .378 | 98.981 |
| **DFI1** | 3235 | 30790353 | 1.163e+08 | 0 | 1.746e+09 |
| **DFI2** | 1850 | 6595.784 | 16835.789 | 44 | 151369 |
| **DFI3** | 1810 | 22715.174 | 79017.047 | 0 | 1110800 |
| **DFII** | 1699 | 0 | 1 | -3.318 | 3.103 |
| **URB** | 3366 | 63.15937 | 19.89789 | 12.621 | 100 |
| **TR** | 3211 | 84.266 | 53.454 | 2.699 | 437.327 |
| **EnU** | 2559 | 2565.139 | 2771.922 | 114.933 | 21420.629 |
| **TEC** | 2555 | 12753.813 | 77538.708 | 1 | 1393815 |
| **FDI** | 3214 | 4.918 | 17.567 | -117.419 | 449.081 |

### *4.3. Correlation Outcomes*

Table 2 presents the correlation outcomes between pairs of variables in the dataset, providing insights into the strength and direction of their linear relationships. Each cell in the table displays the correlation coefficient between two variables, with values ranging from -1 to 1. There is a negative correlation of approximately -0.42 between EnvD and GRG, suggesting that higher levels of green growth are associated with lower levels of environmental degradation. Similarly, correlations between other pairs of variables reveal their interconnections, aiding in understanding potential dependencies and patterns within the dataset.

**Table 2: Correlation Outcomes**

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **(1) EnvD** | 1.00 | | | | | | | | | | |
| **(2) GRG** | -0.42 | 1.00 | | | | | | | | | |
| **(3) DFI1** | -0.02 | -0.13 | 1.00 | | | | | | | | |
| **(4) DFI2** | 0.07 | -0.15 | 0.81 | 1.00 | | | | | | | |
| **(5) DFI3** | 0.19 | -0.14 | 0.70 | 0.77 | 1.00 | | | | | | |
| **(6) DFI** | -0.05 | -0.11 | 0.57 | 0.61 | 0.52 | 1.00 | | | | | |
| **(7) URB** | 0.53 | -0.18 | -0.12 | -0.01 | 0.12 | -0.06 | 1.00 | | | | |
| **(8) TR** | 0.26 | -0.05 | -0.21 | -0.29 | -0.24 | -0.42 | 0.22 | 1.00 | | | |
| **(9) EnU** | 0.76 | -0.16 | -0.07 | 0.01 | 0.11 | -0.19 | 0.56 | 0.22 | 1.00 | | |
| **(10) TEC** | 0.14 | -0.12 | 0.58 | 0.54 | 0.77 | 0.31 | 0.09 | -0.15 | 0.07 | 1.00 | |
| **(11) FDI** | 0.06 | -0.03 | -0.07 | -0.08 | -0.07 | -0.23 | 0.10 | 0.28 | 0.02 | -0.04 | 1.00 |

*4.4. Environmental Degradation Plots*

A Q-Q (Quantile-Quantile) plot is a graphical tool used in statistics to assess whether a dataset follows a certain theoretical distribution, such as a normal distribution. In the context of the Q-Q Plot (Environmental Degradation) depicted in Figure 2, it aims to examine if the distribution of the variable related to environmental degradation conforms to a theoretical distribution, often a normal distribution. The x-axis of the Q-Q plot represents the quantiles of the theoretical distribution, whereas the y-axis displays the quantiles of the observed data. Here, the data points do not lie along a straight diagonal line, it indicates that the data is not normally distributed.

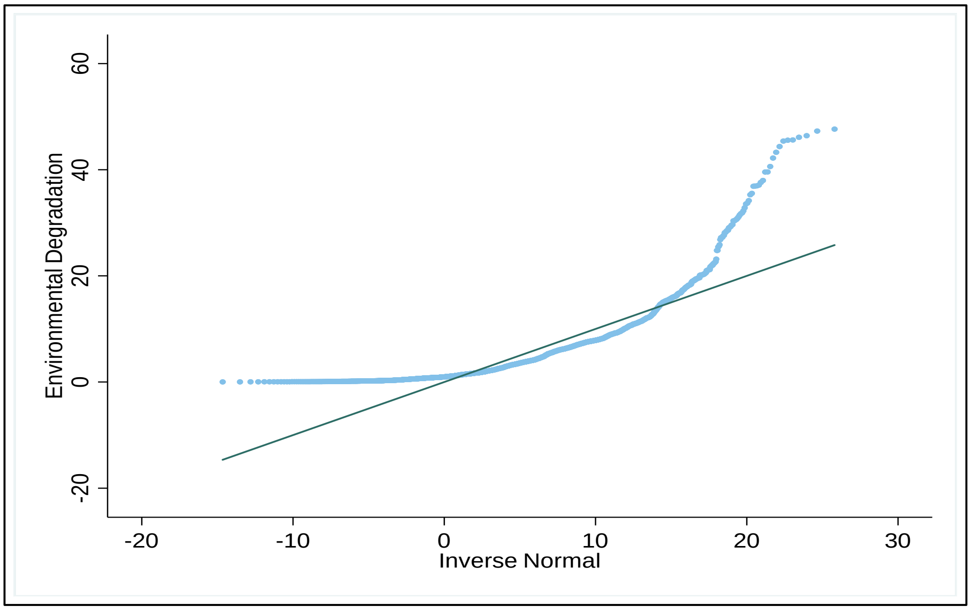


**Figure 2: Q-Q Plot (Environmental Degradation)**

Figure 3 provides an overall visual understanding of how the data on environmental degradation is distributed across various levels, highlighting both the discrete frequency representation through the histogram and the smoothed continuous distribution using the kernel density curve. The rightward skewness of the distribution suggests that there might be a tendency for higher levels of environmental degradation in the dataset.

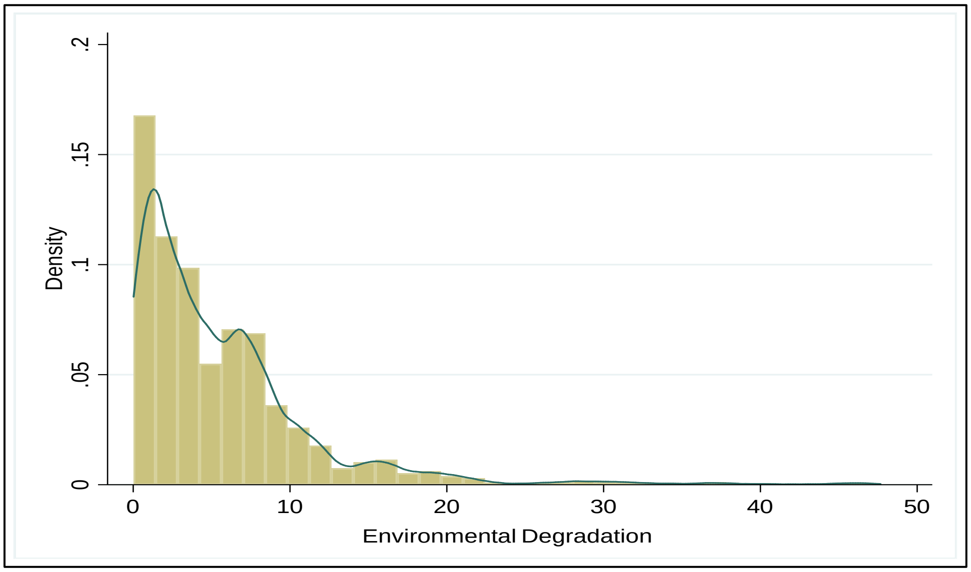


**Figure 3: Histogram with Kernel Density of Environmental Degradation**

*4.5. Results of Quantile GMM*

Table 3 provides the regression outcomes of Model 1 using the MMQR for investigating the association between the outcome variable carbon emissions and various explanatory variables. The table reports the results of POLS and MMQR at different quantiles (τ=25, τ=50, τ=75, and τ=95). Notably, green growth (GRG) demonstrates a consistently negative relationship with environmental quality across different quantiles, with coefficients ranging from -5.554 to -0.440. This reflects that an increase in green growth by a percentage is connected to a decrease in CO2 emissions. This finding implies that green growth aims to align economic growth with environmental sustainability through strategies such as seeking resource efficiency, decoupling economic growth from emissions, and minimizing ecological impact. It focuses on shifting to renewable energy sources (solar, wind, hydro, geothermal) to reduce environmental harm. Moreover, afforestation and reforestation capture and store carbon dioxide, acting as carbon sinks to combat climate change. Eco-friendly infrastructure, including energy-efficient buildings, reduces energy use and emissions. These findings match with the studies of Wei et al. (2023) and Yu et al. (2023) and are also in line with the green growth theory and sustainable development theory. This finding contradicts the EKC theory implications where growth boosts emotions in the early stage of development.

The DFI index has a positive relationship with carbon emissions, presenting that DFI has an unfavorable impact on the environment. This is because the expansion of digital financial services requires energy-intensive digital infrastructure such as data centers, servers, and networks, which, if powered by non-renewable sources, can contribute to higher $CO_2$ emissions. DFI mainly relies on devices such as smartphones and computers, leading to $CO_2$ emissions from energy-intensive manufacturing and disposal. The adoption of electronic devices can pose e-waste management challenges, potentially emitting greenhouse gases if mishandled. Additionally, improved access to digital financial services could stimulate increased economic activity and consumption, driving demand for carbon-intensive goods and services such as transportation and energy-intensive products. This finding is consistent with Mhlanga (2022), Salman & Ismael (2023), and energy economy theory. However, this result is inconsistent with Ding et al. (2022) and Lee et al. (2022) who have demonstrated the carbon-reducing role of DFI for the 30 Chinese provinces and 277 Chinese cities, respectively. Similarly, this result contradicts the study of Liu et al. (2022b) who have concluded that DFI can add to carbon-lessening capability in E7 economies. The likely reason for this inconsistency could be the scope of the study. The carbon-reducing role of DFI is confirmed in a country-specific or a small group of economies where the present study provides a global perspective.

Urbanization (URB), Trade (TR), and Energy Use (EnU) have positive coefficients, indicating a positive relationship with carbon emissions, although the effects vary across quantiles. Urbanization can lead to increased $CO_2$ emissions through various means. Urban areas require more energy for heating, cooling, lighting, and transportation, particularly if reliant on fossil fuels, which can intensify emissions. Mismanaged urban waste, changes in land use, and improved living standards associated with high usage of energy-intensive products all contribute to elevated greenhouse gas emissions. Similar findings are shown by Xin et al. (2023). Trade can increase $CO_2$ emissions due to carbon leakage. This occurs when countries with more stringent environmental regulations relocate production to nations with weaker rules and lower costs, potentially resulting in increased emissions in the latter. Moreover, the transportation of goods across extensive distances in global trade requires energy-intensive shipping, further amplifying $CO_2$ emissions. These results are consistent with Majeed & Mazhar (2020).

Energy consumption is a key driver of increased $CO_2$ emissions as shown in the findings, primarily due to the reliance on fossil fuels (coal, oil, and natural gas). These non-renewable sources used for electricity generation, transportation, and industries, release carbon dioxide into the atmosphere during combustion. The role of technology in carbon emissions varies among countries with different pollution levels. Findings are mixed, implying technology’s impact is not uniform. As countries move higher in quantiles, focusing on clean technology could counter its negative environmental effects. Embracing sustainable technologies becomes crucial for mitigating technology-induced environmental harm. These findings are in line with Li et al. (2021) and Ullah et al. (2021).

In contrast, the impact of FDI yields favorable outcomes, and the coefficient holds significant statistical significance. Hence, a pollution halo hypothesis is verified for the sample economies which assumes that foreign investors may bring advanced technologies, cleaner production methods, and higher environmental standards to host countries. This could lead to a halo effect where FDI improves environmental conditions and reduces pollution levels. Similar findings are reported by Pazienza (2019). Additionally, the location and scale effect provide valuable insights. The location effect is associated with the changes in the regression coefficients across different quantiles of the distribution. A positive location effect indicates that an increase in the independent variable corresponds to an increase in the quantile being examined, while a negative location effect indicates the opposite. Similarly, a scale effect provides insights into how the spread of the distribution varies across quantiles and how it is influenced by the changes in the independent variable. The findings on FDI coefficients are inconsistent with the Pollution Haven Hypothesis (PHH) which states that FDI inflows in developing countries with less stringent environmental rules boost $CO_2$ emissions. Thus, the present study rejects PHH for sample economies. However, this finding is inconsistent with Sabir et al. (2020) who have demonstrated the environmental degrading effect of FDI over the period 1984-2019 in the context of South Asian economies. The present study provides a global perspective while Sabir et al. (2020) findings are limited to South Asian economies.

**Table 3: Results of Model 1**

| Dependent Variable: EnvD (1990-2022) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **POLS** | **MMQR** | | | | | |
| | | **Location** | **Scale** | **τ=25** | **τ=50** | **τ=75** | **τ=95** |
| **Variables** | **Estimated Coefficients** | | | | | | |
| | | | | | | | |
| GRG | -0.554*** | -0.554*** | 0.0638** | -0.605*** | -0.543*** | -0.499*** | -0.440*** |
| | (0.0142) | (0.0304) | (0.0305) | (0.0508) | (0.0255) | (0.0168) | (0.0330) |
| DFII | 0.092*** | 0.0920*** | -0.0316 | 0.117*** | 0.0864*** | 0.0648*** | 0.0357 |
| | (0.00957) | (0.0216) | (0.0216) | (0.0366) | (0.0183) | (0.0120) | (0.0238) |
| URB | 0.736*** | 0.736*** | -0.179** | 0.878*** | 0.704*** | 0.581*** | 0.416*** |
| | (0.0334) | (0.0700) | (0.0703) | (0.115) | (0.0579) | (0.0384) | (0.0751) |
| TR | 0.160*** | 0.160*** | -0.0324 | 0.186*** | 0.154*** | 0.132*** | 0.102*** |
| | (0.0162) | (0.0357) | (0.0358) | (0.0609) | (0.0304) | (0.0199) | (0.0394) |
| EnU | 0.709*** | 0.709*** | 0.105*** | 0.626*** | 0.728*** | 0.799*** | 0.896*** |
| | (0.0192) | (0.0354) | (0.0355) | (0.0575) | (0.0290) | (0.0193) | (0.0376) |
| TEC | 0.0223*** | 0.0223** | -0.0221** | 0.0399** | 0.0184** | 0.00326 | -0.0171 |
| | (0.00513) | (0.0101) | (0.0102) | (0.0169) | (0.00847) | (0.00559) | (0.0110) |
| FDI | -0.0407*** | -0.0407*** | 0.0127 | -0.0508*** | -0.0385*** | -0.0298*** | -0.0182 |
| | (0.00513) | (0.0103) | (0.0103) | (0.0175) | (0.00875) | (0.00573) | (0.0113) |
| Constant | -7.023*** | -7.023*** | 0.325 | -7.280*** | -6.965*** | -6.742*** | -6.443*** |
| | (0.109) | (0.239) | (0.239) | (0.406) | (0.203) | (0.133) | (0.263) |
| Obs. | 1,890 | 1,890 | 1,890 | 1,890 | 1,890 | 1,890 | 1,890 |
| R-squared | 0.937 | | | | | | |

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 4 provides the outcomes of Model 2, which also employs the MMQR approach to explore the impact of different measures of DFI on environmental degradation. Here also, the table shows the results obtained from two estimation methods: POLS and MMQR, across various quantiles (percentiles), denoted as τ values, specifically τ=25, τ=50, τ=75, and τ=95. Similar to the previous model, the findings here indicate that variable green growth consistently exhibits a negative relationship with carbon emissions across different quantiles. In other words, regardless of whether we are considering the lower 25th percentile, the median (50th percentile), the 75th percentile, or the higher 95th percentile of the distribution, the coefficient associated with GRG remains negative. This suggests that an increase in GRG is consistently associated with a decrease in environmental pollution across the entire spectrum of quantiles.

However, the results in the upper quantiles of the distribution (such as τ=75 and τ=95) show a more pronounced or larger effect of the variable GRG on carbon emissions. This suggests that the influence of GRG on environmental degradation is more substantial in countries with higher levels of existing pollution. This trend aligns with the idea that countries with higher existing pollution levels might be more sensitive to changes in certain factors like GRG, as they could potentially be closer to critical thresholds where even small changes can lead to disproportionately larger environmental effects. The findings are in line with Wei et al. (2023), Yu et al. (2023), green growth theory, and sustainable development theory.

The impact of DFI on environmental degradation differs depending on the specific characteristics or aspects of DFI that are being considered. The variability in the effects of different "DFI" measures suggests that the relationship between DFI and environmental degradation is not uniform; rather, it depends on specific characteristics or dimensions of DFI. For instance, the coefficients of mobile cellular subscriptions (DFI1) are negative and statistically significant. This suggests that an increase in mobile cellular subscriptions is associated with a reduction in CO2 emissions. This could be attributed to several factors. For example, mobile communication might lead to increased efficiency in business processes, thereby reducing the need for physical travel and transportation. Additionally, mobile technology could enable better resource management and coordination, potentially resulting in reduced energy consumption and emissions. While the effects of commercial bank branches (DFI2) and automated teller machines (DFI3) are positive and significant. This could be due to a few reasons. The expansion of banking services might be linked to increased economic activity, which could result in more transportation, energy consumption, and industrial production—all contributing to higher CO2 emissions. This finding is in line with Mhlanga (2022) and Salman & Ismael (2023). This finding supports the energy economy theory.

Further, the study's findings reveal that URB, TR, EnU, and TEC exhibit primarily positive impacts on CO2 emissions. These results resonate with the existing body of literature and maintain congruence with the outcomes observed in the initial model. The positive influence of URB on emissions aligns with the urban heat island effect, where intensified human activities and infrastructure concentration in urban areas amplify energy consumption and thus CO2 emissions. Similarly, the positive relationship between trade and emissions reflects the well-documented connection that less-energy efficient product usage, results in elevated emissions. The positive impact of EnU on emissions underlines the pivotal role of energy consumption as a significant contributor to greenhouse gas emissions.

Furthermore, the positive influence of TEC on emissions highlights the complex interplay between technological advancements, increased energy use, and emissions. Lastly, the analysis maintains the negative relationship between FDI and carbon emissions. This finding aligns with the broader understanding that foreign investment often brings about technological transfer, improved efficiency, and more environmentally friendly practices, which collectively contribute to a reduction in carbon emissions. The alignment of these outcomes with prior research and the consistency observed across the first model bolsters the reliability of the present study's findings.

**Table 4: Results of Model 2**

| Dependent Variable: EnvD (1990-2022) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **POLS** | **MMQR** | | | | | |
| | | **Location** | **Scale** | **τ=25** | **τ=50** | **τ=75** | **τ=95** |
| **Variables** | **Estimated Coefficients** | | | | | | |
| | | | | | | | |
| GRG | -0.668*** | -0.668*** | 0.0792*** | -0.728*** | -0.654*** | -0.603*** | -0.532*** |
| | (0.0239) | (0.0279) | (0.0226) | (0.0409) | (0.0252) | (0.0215) | (0.0298) |
| DFI1 | -0.082*** | -0.082*** | 0.00605 | -0.0868*** | -0.0812*** | -0.0773*** | -0.0718*** |
| | (0.0141) | (0.0199) | (0.0161) | (0.0292) | (0.0182) | (0.0154) | (0.0216) |
| DFI2 | 0.0431*** | 0.0431*** | -0.0221 | 0.0598** | 0.0392** | 0.0250* | 0.00502 |
| | (0.0164) | (0.0167) | (0.0135) | (0.0245) | (0.0152) | (0.0129) | (0.0181) |
| DFI3 | 0.0915*** | 0.0915*** | 0.00741 | 0.0859*** | 0.0929*** | 0.0976*** | 0.104*** |
| | (0.0172) | (0.0197) | (0.0160) | (0.0289) | (0.0181) | (0.0152) | (0.0214) |
| URB | 0.789*** | 0.789*** | -0.228*** | 0.962*** | 0.749*** | 0.602*** | 0.396*** |
| | (0.0488) | (0.0615) | (0.0498) | (0.0898) | (0.0549) | (0.0471) | (0.0651) |
| TR | 0.276*** | 0.276*** | -0.108*** | 0.357*** | 0.257*** | 0.187*** | 0.0901** |
| | (0.0269) | (0.0337) | (0.0273) | (0.0493) | (0.0303) | (0.0259) | (0.0359) |
| EnU | 0.622*** | 0.622*** | 0.113*** | 0.537*** | 0.642*** | 0.715*** | 0.817*** |
| | (0.0272) | (0.0331) | (0.0268) | (0.0483) | (0.0296) | (0.0253) | (0.0351) |
| TEC | 0.00674 | 0.00674 | -0.0202** | 0.0220 | 0.00315 | -0.00983 | -0.0281** |
| | (0.00762) | (0.0107) | (0.00865) | (0.0156) | (0.00971) | (0.00823) | (0.0115) |
| FDI | -0.0449*** | -0.0449*** | 0.0281*** | -0.0662*** | -0.0399*** | -0.0219** | 0.00352 |
| | (0.0111) | (0.0118) | (0.00961) | (0.0174) | (0.0108) | (0.00914) | (0.0128) |
| Constant | -6.515*** | -6.515*** | 0.728** | -7.065*** | -6.386*** | -5.919*** | -5.261*** |
| | (0.299) | (0.389) | (0.315) | (0.570) | (0.354) | (0.300) | (0.420) |
| Obs. | 857 | 857 | 857 | 857 | 857 | 857 | 857 |
| R-squared | 0.934 | | | | | | |

The graphical depiction of regressors across quantiles, presented in Figure 4, offers valuable insights into the comparative estimation results. The long-dashed line within the plot corresponds to the coefficients derived from the POLS estimation. This line remains consistent, accompanied by confidence intervals denoted by subtle dotted lines, indicating the stability of P OLS estimates across quantiles. In contrast, the coefficients obtained through the MMQR approach are visualized as a grey-shaded region. Strikingly, these MMQR coefficients deviate beyond the dotted lines, exposing a clear disparity between the POLS and MMQR results. This divergence signifies a potential bias in the POLS findings that becomes evident under the MMQR approach.

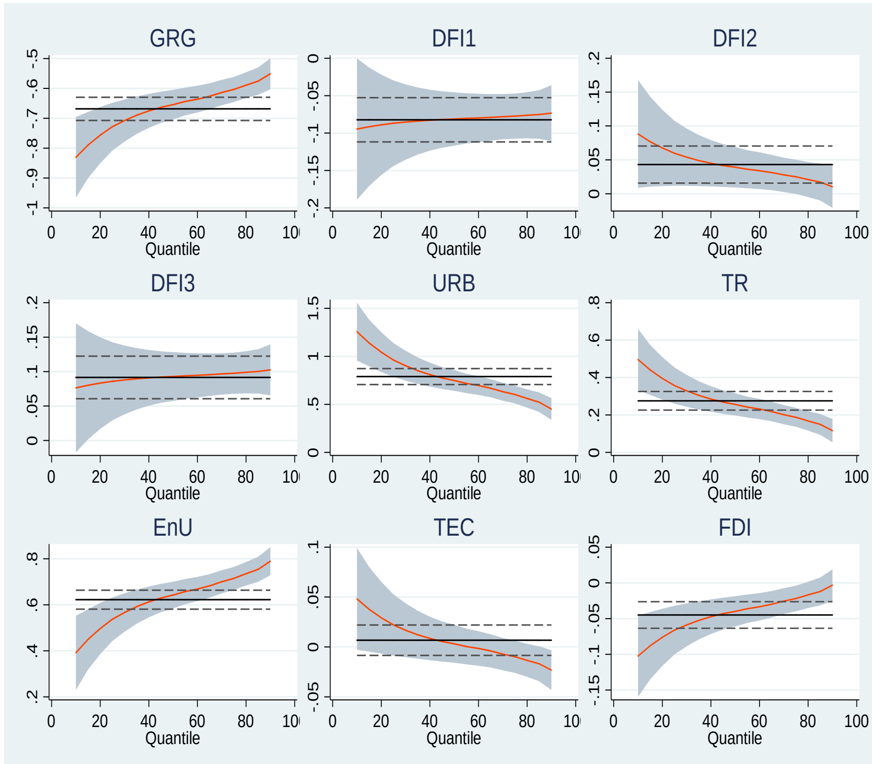


**Figure 4: Regression plots (By Quantiles)**

## 5. Conclusion

This study analyzes the environmental effects of DFI and green growth using panel data from 102 countries with a time frame of 1990-2022. The study used mobile cellular, bank branches, and ATM cards as proxy variables of DFI. Moreover, an index of DFI is constructed using Principal Component Analysis. The study used conventional estimation POLS including a novel estimation technique MMQR. The results suggest green economic growth helps to improve environmental quality while DFI escalates environmental degradation. However, different measures of DFI exert different effects. The favorable effects of DFI on CO2 emissions are mainly transmitted through mobile cellular subscriptions. The empirical outcomes are in line with past studies and theoretical outlooks. The study also shows that control variables play an important role in influencing environmental quality.

### *5.1 Contribution of the Study*

To our knowledge, no past study has investigated the comparative effects of DFI on carbon emissions in the context of the global economy. By incorporating three different measures of DFI—mobile subscriptions, commercial banks, and the number of ATMs—the study provides more holistic insights into the association between DFI and environmental quality. Furthermore, this study also constructs a composite index to provide a more compact picture of the association between DFI and environmental quality. The inclusion of green growth as a focus of investigation alongside DFI enhances its relevance to current sustainability challenges. By examining the DFI, green growth, and environmental quality, the study addresses a critical gap in the literature and offers insights into how financial inclusion can be aligned with environmental goals. The study contributes methodologically by using the MMQR approach. This technique offers a nuanced analysis of the distributional effects, allowing for a deeper understanding of how DFI's impact on environmental quality might vary across different levels of distribution.

### *5.2 Usefulness of the Study*

Through its comprehensive analysis and methodological advancements, the study provides insights that can inform policy decisions aimed at fostering sustainable development. Policymakers can use the study’s findings to design strategies that promote both DFI and green growth, while also considering potential trade-offs and variations across different segments of the population. Particularly, environmental policies need to be designed considering the importance of green growth for environmental conservation. The results have demonstrated the robustly favorable role of green growth for environmental quality. In respect, the use of green technologies can be encouraged by providing subsidies for green technologies and removing/lowering taxes on industries related to environmental preservation.

### *5.3 Theoretical Contribution*

The empirical outcomes of this research shows that DFI is linked to a noticeable decline in overall environmental quality. This outcome contrasts with the ecological modernization and environmental transition theories which predict that technological improvements, innovations, and modernization help to resolve issues associated with the environment and improve environmental quality. An improvement in DFI facilitates technological and financial support to firms, encouraging them to adopt clean energy technology in the production process. The use of environmentally friendly technologies helps to conserve the environment. The results also support the pollution halo hypothesis. This study’s findings also confirm the sustainable development theory, green growth theory, and energy economy theory.

### *5.4 Research Limitations and Future Research Direction*

This study has certain shortcomings which can be addressed by future research. First, this study focused on global analysis, however, the data for all global economies was not available. Hence, the data shortcomings can undermine the strength of empirical outcomes. This study mainly focused on CO2 emissions whereas other forms of GHG emissions may have different associations with DFI. This study used three measures of DFI, whereas future research can use other measures as well. To capture the full concept of DFI measures such as mobile money account holders, mobile money transaction value, and number of digital devices are important. However, these measures are not included in this study due to data limitations for panel data analysis. Future research can consider these measures in a cross-sectional analysis, country-specific analysis, and some other country classification for which data is available. The study suggests that future research can assess the role of FinTech in determining environmental quality. Moreover, suture research can focus on financial instability, financial institutions, and financial efficiency in observing the environmental effects of the financial sector.

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## Appendix: A1

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|---|---|---|---|---|
| Albania | Costa Rica | Indonesia | Morocco | Slovak Republic |
| Algeria | Croatia | Iran, Islamic Rep. | Mozambique | Slovenia |
| Argentina | Cyprus | Israel | Netherlands | South Africa |

| | | | | |
|---|---|---|---|---|
| Armenia | Czechia | Italy | New Zealand | Spain |
| Australia | Denmark | Jamaica | Nicaragua | Sudan |
| Austria | Dominican Rep. | Japan | Nigeria | Sweden |
| Azerbaijan | Ecuador | Jordan | North Macedonia | Switzerland |
| Bangladesh | Egypt, Arab Rep. | Kazakhstan | Norway | Tajikistan |
| Belgium | Estonia | Kenya | Pakistan | Thailand |
| Bolivia | Ethiopia | Kyrgyz Republic | Panama | Tunisia |
| Bosnia-Herzegovina | Finland | Latvia | Paraguay | Turky |
| Botswana | France | Lebanon | Peru | Ukraine |
| Brazil | Georgia | Lithuania | Philippines | UAE |
| Brunei Darussalam | Germany | Luxembourg | Poland | United Kingdom |
| Bulgaria | Greece | Malaysia | Portugal | United States |
| Cambodia | Guatemala | Malta | Qatar | Uruguay |
| Canada | Haiti | Mauritius | Romania | Vietnam |
| Chile | Honduras | Mexico | Russian Federation | Zambia |
| China | Hungary | Moldova | Saudi Arabia | |
| Colombia | Iceland | Mongolia | Serbia | |
| Yemen, Rep. | India | Montenegro | Singapore | |