Journal of Open Innovation: Technology, Market, and Complexity 10 (2024) 100371

Contents lists available at ScienceDirect

Journal of Open Innovation: Technology, Market, and Complexity

journal homepage: www.sciencedirect.com/journal/journal-of-open-innovation-technology-market-and-complexity

Do fintech, natural resources and globalization matter during ecological crises? A step towards ecological sustainability

Kingsley I. Okere [a,*,1], Stephen Kelechi Dimnwobi [b,2], Ismail O. Fasanya [a,3]

[a] School of Economics and Finance, University of the Witwatersrand, Johannesburg, South Africa
[b] Department of Economics, Nnamdi Azikiwe University, Awka, Nigeria

ARTICLE INFO

Keywords:
Environmental sustainability
FinTech
Natural resources
Globalization
North Africa

ABSTRACT

The rate of biodiversity loss and forest depletion has surged significantly, primarily driven by the substantial increase in worldwide environmental deterioration. This alarming development is nearing the critical temperature limit of 2 °C, necessitating increased scrutiny. This study therefore adopts the Load Capacity Curve framework that amalgamates these concepts, offering a guide for implementing a robust and sustainable adaptation plan in the North African region. The research utilized data spanning from 1991 to 2022 and employed advanced quantitative methods, including quantile regression (QR), augmented mean group (AMG), and the Half-Panel Jackknife (HPJ) Wald-type test, to explore causality. The empirical findings challenge the notion of a U-shaped relationship between per capita GDP and ecological load capacity, revealing instead an inverted U-shaped pattern at the 25th and 50th quantiles. Additionally, the study identifies a negative and significant association between natural resource rents and globalization with the ecological load capacity factor, indicating a detrimental effect. On the other hand, Fintech demonstrates a statistically significant and positive impact on environmental sustainability, indicating a mitigating effect. Causality tests further reveal bidirectional causality between ecological load capacity and per capita GDP, GDP squared, and Fintech, while a unidirectional positive relationship exists between globalization and ecological load capacity. Based on these findings, the study puts forth several policy recommendations to support informed decision-making.

1. Introduction

The dire condition of worldwide environmental deterioration requires urgent measures to avert additional disastrous occurrences (Ali et al., 2023a; Ezenekwe et al., 2023, Avcı et al., 2024, Udemba et al., 2024). The adverse effects of environmental degradation are already being observed on Earth (2022; Okere et al., 2023a). There has been a substantial increase in the rate at which species are becoming extinct, with over 32,000 species being at risk of extinction (IUCN, 2023). Moreover, the swift depletion of more than 420 million hectares of forest from 1990 to 2020 is a matter of profound apprehension (FAO, 2020). Furthermore, the tendency for mean surface temperatures (MST) to approach the 2°C threshold has led to a rise in severe heatwaves, heightened the occurrence and intensity of extreme weather phenomena, and played a role in the escalation of sea levels and coastal flooding (Alvarado et al., 2022; Cetin et al., 2023, Opoku-Mensah et al., 2023, Dagar et al., 2024). This expansion in environmental contamination is concerning particularly as it relates to the attainment of Sustainable Development Goals (SDGs) and guaranteeing enduring sustainability (Dimnwobi et al., 2022a, Rao et al., 2023, Cetin et al., 2024). Several SDGs can be hindered by an increase in ecological degradation. For instance, ecological decay influences SDG 3 by increasing health concerns like cardiovascular and respiratory issues. It also taints water bodies, hence influencing SDG 6's drive for sanitation and clean water. The utilization of fossil fuels degrades the air quality which puts SDG 7's sustainable energy objectives at risk (Kumar et al., 2024, Okere et al., 2023b, Onuoha et al., 2023a, Raghavendra et al., 2024). The SDG's 11 target of promoting sustainable cities is also undermined by urban pollution while the increasing patterns of inefficient resource use which expands pollution levels obstructs responsible consumption (SDG 12).

* Corresponding author.
E-mail addresses: kingsley.okere@wits.ac.za (K.I. Okere), ismail.fasanya@wits.ac.za (I.O. Fasanya).
[1] Orcid: https://orcid.org/0000–0002-1845–4583
[2] https://orcid.org/0000–0002-5964–9627
[3] https://orcid.org 0000–0001-5816–4815

https://doi.org/10.1016/j.joitmc.2024.100371

Available online 31 August 2024

Finally, pollution expands climate change, hindering SDG 13's climate action efforts (Ozturk et al., 2022, Onuoha et al., 2023b, Omoju et al., 2024). The reduction in pollution levels has been a major priority for several economies across the globe and scholars have been assessing the predictors of environmental degradation. Understanding the sources and drivers of ecological damage is essential to advancing broader goal of sustainability and attaining SDGs. Hence, studies on ecological sustainability is desirable as it assists with the initiatives for the establishment of a healthier and greener world.

Fintech has significantly reshaped the financial and business landscape in the last decade, incorporating various elements such as cryptocurrencies, blockchain, mobile payments, online banking and crowdfunding (Zhang et al., 2024). Fintech has been acknowledged for its potential to expand financial accessibility, democratize financial services, and stimulate economic advancements (Sadiq et al., 2023). A key advantage of Fintech in connection with climate change is its facilitation of green funding and sustainable expansion through tools like carbon credit trading, green bonds, and loans for renewable energy (Udeagha and Ngepah, 2023). Climate change could gain from the potential for enhanced energy efficiency offered by Fintech (Kong and Xu, 2023). However, the infrastructure and devices related to Fintech are impermanent and require high energy consumption. Harmful substances present in electronic waste accumulate rapidly. When electronic waste is incinerated or decomposes in a landfill, it emits toxic chemicals that add to carbon emissions. Moreover, the use of data centres, high-speed internet, and cloud computing by Fintech can amplify energy usage and carbon emissions (Lisha et al., 2022).

The presence of natural resource rents has the potential to both positively and negatively influence environmental quality. Specifically, these rents may result in investments in environmental conservation and protection (Usman and Balsalobre-Lorente, 2022). This outcome is more likely to materialize when governments assign a portion of resource earnings to support environmental programs (Adebayo et al., 2023). On the other hand, as per the resource curse theory, excessive dependence on natural resource rents can lead to detrimental environmental practices like excessive extraction and pollution (Jahanger et al., 2022). Furthermore, it may contribute to the neglect of other economic sectors, resulting in environmental degradation and loss of biodiversity. Hence, effective management of natural resource rents is essential to minimize adverse effects and optimize positive influences on environmental quality (Luo and Mabrouk, 2022). The environmental implications of globalization have become a significant area of research interest. Supporters of globalization argue that increased globalization correlates with reduced environmental harm (Miao et al., 2022; Cetin et al., 2023). They claim that globalization imposes strict environmental regulations on companies, thereby decreasing their pollution levels (Rasool et al., 2023). Conversely, opponents of globalization assert that heightened globalization levels lead to diminished environmental quality (Xu et al., 2022). They argue that globalization results in a greater number of companies broadening their operations and elevating their production levels (Le and Ozturk (2020). This surge in production is linked to heightened energy requirements, thereby amplifying energy consumption and subsequently leading to environmental degradation (Hussain and Zhou, 2022)

The study zeroes in on the North African region for a multitude of compelling reasons. First, excluding Sudan and Libya, North African countries rank among the largest economies in Africa (Adun et al., 2022; Musah et al., 2022). While recent challenges have affected Sudan and Libya, other nations in the region are undergoing rapid growth and are expected to outpace the growth rates of several other African economies due to their substantial economic activities (Musah et al., 2022). Unfortunately, this surge in economic activity has coincided with declining environmental conditions, positioning North Africa as one of the most polluted regions on the continent (Shouwu et al., 2024). Three of the top five emitters in Africa are situated in this area, largely due to its heavy reliance on non-renewable energy sources (Adun et al., 2022).

Secondly, the impact of globalization, involving integration with the global community, has enabled the region to access new investments and technology transfer (Aladejare, 2022). The expansion of interactions with other nations brings various advantages, including knowledge sharing, fostering economic interdependence, technology transfer, and influencing people's ways of life (Karaduman, 2022). Consequently, the region has witnessed substantial growth in globalization over recent decades, driven by its pursuit of economic advancement (Zeraibi et al., 2023). This growth suggests that the pollution halo hypothesis is highly relevant in North African economies, as foreign investment and trade continue to rise due to the impact of globalization (Aladejare, 2022). However, despite the positive impacts of globalization, associated economic activities could contribute to global warming, resulting in detrimental outcomes for the environment. For instance, the use of environmentally harmful industrial practices and reliance on traditional energy sources significantly increase pollution through higher greenhouse gas emissions (Hussain and Zhou, 2022). Therefore, understanding the significant impact of the increasing trends in globalization on environmental degradation in the region is imperative. Thirdly, North African countries are known for their abundant natural resources (Adun et al., 2022). Algeria's primary exports comprise 93.6 % of oil and natural gas, positioning it as one of the top three oil producers in Africa (Khraief et al., 2018). Egypt boasts significant oil and natural gas reserves, making it the largest non-OPEC oil nation (Adun et al., 2022). Libya, another key oil producer in North Africa, currently produces 1.4 million barrels of oil daily, with proven crude oil reserves of about 47.1 billion barrels and a natural gas reserve of approximately 52.8 cubic meters (Adun et al., 2022). Tunisia heavily relies on natural gas and petroleum reserves, generating approximately 87,404.63 million cubic feet (MMcf) of natural gas annually (Attig-Bahar et al., 2021). These abundant resources have prompted global concern owing to their negative environmental impact, particularly with climate change. This influence is analogous to the far-reaching impact of prior global financial crises, which initially emerged in a single region before spreading globally (Sakariyahu et al., 2023). As a result, the North African region may not be entirely insulated from these effects, despite its lower contribution to global warming compared to developed nations. Lastly, North African countries have seen the emergence of creators and innovators utilizing technology to offer a range of financial services and benefits to the local population. In 2020, Egypt hosted 14 % of the fintech firms in Arab nations, with Morocco closely following at 13 %. Additionally, Tunisia accounted for a 9 % share of the total number of fintech companies in the region (Statista, 2023). The increasing rate of fintech startup activities in the region could potentially lead to significant ecological challenges.

The foregoing highlights the criticality of assessing the influence of Fintech, natural resource rent, economic growth and globalization on ecological preservation in North Africa. Our interest in this area is motivated by the fact that despite the increasing importance of Fintech in promoting economic advancements and financial inclusion, its effects on ecological quality are yet to be given research attention in the North African region. Hence, this study bridges this gap by assessing the influence of Fintech on ecological preservation. Additionally, this study appraises the influence of natural resource rent in shaping ecological performances in the region. Although resource rents can propel economic progress, they can also contribute to ecological decay if not sustainably managed. Hence, we uncover if resource rent can stimulate or undermine ecological integrity. Furthermore, this study also appraises the effect of globalization and economic growth in either advancing or exacerbating ecological decline in the bloc. This study offers a holistic comprehension of these variables on environmental protection hence documenting valuable insights for decision-makers in this region. Hence, this study answers these pertinent questions: (1) What is the effect of economic advancement on environmental quality in North Africa and if the load capacity curve (LCC) hypothesis exists in this region? (2) Does Fintech stimulate or impede ecological preservation in

North Africa? (3) Can natural resource rent lessen ecological decay or boost ecological health in North Africa? (4) How does globalization influence North Africa's environmental performance?

Given the foregoing discussions, our study makes significant contributions across various dimensions.

1. Previous studies, such as those by Jahanger et al. (2022), Usman and Balsalobre-Lorente (2022), Udeagha and Ngepah (2023), Usman et al. (2022), and Zhao et al. (2022), have predominantly relied on metrics like carbon emissions, methane emissions, greenhouse gas emissions, and ecological footprints to assess environmental sustainability. However, these metrics face criticism from Ezenekwe et al. (2023) and Lin and Ullah (2024) for their limited emphasis on specific ecological issues rather than providing holistic assessments. Recognizing the need for a more inclusive measure, the load capacity factor (LCF) has emerged as a suitable statistic, as highlighted by Du et al. (2024) and Villanthenkodath and Pal (2024). They found it to be a unique indicator revealing the limits ecosystems can bear before experiencing stress that hinders the replenishment and sustenance of both ecosystems and human well-being. Using the LCF as a gauge for environmental quality is deemed crucial due to its ability to account for various aspects of resource consumption and ecological stress
2. North African economies are very keen to attain carbon neutrality as well as several SDGs, hence developing robust strategies is crucial and there is an urgent need to assess recent theories that can assist in crafting comprehensive policies. Hence this study documents the first research endeavor at assessing the validity of the LCC hypothesis in the region. LCC illustrates an event contrary to the Environmental Kuznets Curve (EKC) hypothesis and indicates a U-shaped connection between income and LCF. The utilization of this LCC concept as well as a comprehensive environmental indicator, we can assess the performance of North African economies, since the achievements of most SDG targets are majorly hinged on the environmental sustainability
3. Contrary to prior studies that predominantly utilized traditional mean regression approaches, this study applied quantile regression (Methods of Moments of Quantile Regression and bootstrapped Simultaneous Quantile Regression) because of its qualities to provide more elaborate outcomes. Additionally, the Augmented Mean Group (AMG) was also employed to obtain findings across aggregate and country levels. We also utilized the Half-Panel Jackknife (HPJ) Wald-type test to assess the causality between the variables of the study.
4. The latest datasets are utilized in this research. Hence, this study aside from providing the most recent insights on this issue in the literature, will assist in unearthing the major factors contributing to ecological quality. This will aid in crafting tailored strategies to protect the environment

The subsequent segment presents perspectives from the literature, complemented by data and empirical methodologies (refer to Section 3). Section 4 delineates the study's outcomes culminating in the inquiry's conclusion in Section 5.

2. Literature review

2.1. Theoretical insights

The EKC hypothesis forms the theoretical basis for understanding the correlation between economic growth and environmental well-being. Grossman and Krueger (1991) were instrumental in introducing the EKC concept to examine the influence of economic growth on ecological health. According to the EKC theory, during the initial phases of economic progress, environmental pressures intensify as income levels increase. However, once a certain income threshold is achieved, these pressures decline (Dimnwobi et al., 2023a, 2023b). Similar to the EKC theory, the LCC proposition suggests a U-shaped relationship between economic advancement and the load capacity factor. Notably, the LCC posits an evolving scenario in which increased income initially diminishes ecological load capacity in the short term but enhances it in the long term (Deng et al., 2024; Fang et al., 2024).

2.2. Empirical evidence

We have segmented the empirical literature review into three distinct strands, specifically focusing on their associations with environmental quality

2.2.1. Natural resources-environment nexus

The excessive exploitation and usage of natural resources have resulted in a troubling escalation of ecological deterioration and resource depletion. Despite being recognized as an economic catalyst that drives economic growth, enhances the financial system, and improves the quality of life, natural resources come at the cost of compromising ecological balance. Consequently, the existing literature demonstrates a conflicting discourse regarding the interplay between natural resource utilization and ecological preservation. One perspective suggests that natural resources contribute to ecological decay through unsustainable exploitation and utilization during periods of economic boom. For instance, Li et al. (2022) explore the influence of natural resources on the ecological footprint within the Arctic region, concluding that natural resources exacerbate the ecological footprint. Usman et al. (2022) arrive at analogous conclusions within the same region. Luo and Mabrouk (2022) focus on economies abundant in natural resources and find that natural resources significantly increase ecological decline. This is primarily attributed to the traditional technology employed in the processes of extracting and consuming natural resources. In a wider setting, Jahanger et al. (2022) validate this finding by demonstrating that natural resources lead to a significant escalation in the ecological footprint across 73 developing countries. Relatedly, Zhao et al. (2022) observe comparable outcomes in advanced countries, where they report that natural resources exert a strong influence on the intensification of the ecological footprint. The role of natural resources in hindering sustainable ecosystem aligns with the outcomes of country-level studies including China (Afshan and Yaqoob, 2022); Saudi Arabia (Agboola et al., 2021) and India (Hossain et al., 2022)

An alternative perspective supports the notion that natural resources play a beneficial role in mitigating environmental decline. As an example, Adebayo et al. (2023) demonstrate the positive environmental effects of natural resources in BRICS, achieved by increasing the share of renewable energy and reducing the use of fossil fuels in the energy mix. Likewise, Kongbuamai et al. (2020) and Xiaoman et al. (2021) confirm that natural resources significantly enhance environmental well-being in ASEAN and MENA nations respectively. This is also similar to the outcome obtained in newly advanced economies (Usman and Balsalobre-Lorente, 2022), EU-5 countries (Balsalobre-Lorente et al., 2018), Gulf Cooperation Council countries (Majeed et al., 2021) as well as in country level studies including the United States (Khan et al., 2021) and Pakistan (Zhang et al., 2021). These studies affirm that natural resources contribute to environmental quality by limiting pollution

In light of the empirical results from prior research, we have observed the uncertain link between natural resources and environmental decline. This leads to the first testable hypothesis, which is articulated as follows:

Natural resources have a significant impact on environmental deterioration in the North African region.

2.2.2. Globalization-environment nexus

Research on the connection between globalization and environmental pollution frequently draws from the pollution haven hypothesis and the pollution halo hypothesis. The pollution-haven hypothesis suggests that due to globalization, inadequate environmental regulations in developing nations draw foreign industries, resulting in heightened pollution. This theory argues that although this may spur economic advancement, it also markedly adds to ecological decay (Ali et al., 2023b). Advocates of the pollution-halo hypothesis maintain that, due to globalization, nations with stringent environmental policies draw environmentally responsible industries, resulting in lower emissions. They contend that failure to adhere to the environmental regulations of the host country may lead to significant fines and penalties for the industries (Ahmed et al., 2020)

Several studies have substantiated the pollution halo hypothesis through the use of either country-level or regional-level data. For instance, Erdoğan et al., (2020), Adjei et al (2022) and Aladejare (2022) confirm that globalization leads to improved environmental quality in African economies. In emerging economies, Onifade et al. (2021) and Çetin et al. (2023) disclose that globalization diminishes ecological degradation. This also supports the outcome in the MENA region (Awan et al., 2020), resource-rich economies (Usman et al., 2021), newly industrialized countries (Karaduman, 2022) and developed economies (Miao et al., 2022). Additionally, Rasool et al. (2023) establish that social globalization alleviates environmental degradation in Indonesia

Some studies report that the ecosystem development is impaired by globalization thereby supporting the pollution-haven hypothesis. For instance, Sabir and Gorus (2019) and Wen et al. (2021) report that globalization leads to increased ecological decay in Asia. This is also related to the conclusions of Wang et al. (2020) in G7 economies and Xu et al. (2022) in the five largest economies revealing the exacerbating impact of globalization on the environment. Additionally, Le and Ozturk (2020) and Hussain and Zhou (2022) confirm that globalization increases environmental degradation in 47 economies and Belt and Road Initiative economies respectively. Etokakpan et al. (2020) confirm globalization's long-term pollutive impact on the Turkish economy while Murshed et al. (2022) establish that economic globalization exacerbates environmental pollution in Argentina

The literature lacks a consistent consensus on the impact of globalization levels on ecological degradation. Empirical outcomes are significantly influenced by the methodologies employed, periods considered, countries included, and the specific pollution indicators utilized. Furthermore, country-specific elements, including the ecological policies stringency, economic structure and fossil fuel taxes may influence how globalization affects environmental quality. The preceding discussions lead to the formulation of the second testable hypothesis as follows:

The process of globalization has a significant impact on the environmental degradation of the Northern African region.

2.2.3. Fintech-environment nexus

The global financial markets have grown significantly due to innovative financial technologies, transforming the industry and impacting economies and the environment. Fintech assists businesses and individuals with managing financial processes using technologies like AI and mobile apps. It also has the potential to analyze waste generation and guide investments towards eco-friendly products using advanced technologies. This has sparked increased research interest in the link between Fintech and ecological sustainability (Karim et al., 2022). For instance, Udeagha and Ngepah (2023) between 2000 and 2018, Udeagha and Muchapondwa (2023a) and Udeagha and Muchapondwa (2023b) both from 1990 to 2020 find that Fintech is essential in attaining carbon neutrality in BRICS economies. This outcome is also in alignment with the outcomes of Asia (Dong et al., 2023), Belt and Road nations (Li et al., 2023) and G7 economies (Xia and Liu, 2024). Numerous Chinese studies (Muganyi et al., 2021; Cheng et al., 2023; Deng and Dong, 2024; Guo et al., 2023; Sadiq et al., 2023; Liu et al., 2024) conclude that the advancement of Fintech plays a significant role in contributing to environmental conservation. This consensus is further substantiated by studies conducted in other regions, such as the research by Nenavath (2022) focusing on India.

On the flip side, in a contrasting study, Lisha et al., (2022) appraise the influence of Fintech on carbon emissions within the BRICS region from 2000 to 2019. Their results indicate that Fintech undermines environmental quality by elevating carbon emissions from lower to higher emissions quantiles. The direct link between fintech and increased emissions stems from the substantial energy consumption involved in mining Bitcoin, which predominantly relies on non-renewable energy sources such as thermal plants and coal resulting in significant emissions and contributing to detrimental pollution.

Consequently, the relationship between fintech and the environment remains a topic of debate, necessitating further research to establish pathways for sustainable development. This brings us to the third testable hypothesis, outlined as follows:

Fintech significantly affects North Africa's environmental degradation

2.3. Literature gaps

A thorough survey of prior related studies highlights extensive investigations into the key factors shaping ecological quality. However, there is a noticeable dearth of research examining how Fintech, natural resources, and globalization collectively contribute to environmental concerns in the North African region. Consequently, our study aims to address this knowledge gap in the existing literature by reassessing the connection between Fintech, natural resources, and globalization. We explore their role in mitigating ecological decline through the application of advanced techniques namely AMG, MMQR, and BSQR approaches. Furthermore, while many environmental scholars have utilized carbon dioxide emissions as a measure of environmental quality, however, this metric has been viewed by environmental scholars as an oversimplified and narrow assessment of environmental health. In contrast, some studies favour the ecological footprint, which encompasses six distinct facets of ecological damage, providing a more comprehensive assessment of environmental sustainability. The ecological footprint illustrates the manifestation of human impact on the environment through the utilization of natural resources. Both carbon dioxide emissions and ecological footprint cover only the demand side of nature. Therefore, using a more comprehensive environmental measure becomes pertinent. This study employs the load capacity factor, as proposed by Siche et al. (2010) to enhance the comprehensiveness of the analysis. This metric offers a comprehensive evaluation of environmental dynamics by concurrently considering both demand and supply factors. The analysis takes into account biocapacity and ecological effects, providing insights into the sustainability of the environment. Recently, some scholars have recognized the load capacity factor as a comprehensive metric for environmental performance (Ezenekwe et al., 2023; Deng et al., 2024; Du et al., 2024; Fang et al., 2024; Lin and Ullah, 2024; Villanthenkodath and Pal, 2024). However, their scrutiny has predominantly overlooked the influence of natural resources, Fintech, and globalization in determining the load capacity factor within the North African region.

3. Model, data and regression techniques

3.1. Construction of the empirical model

Environmental decay can result from a variety of human-created, technological, and structural situations, as detailed in the paradigm proposed by Dietz and Rosa (1994). Considering this, we factor in extra variables when specifying our model for the empirical investigation. First, we examined the environmental implications of population growth from an environmental standpoint. Research has demonstrated a direct link between the expansion of population and the degradation of ecosystems, which aligns with the Malthusian theory. This theory posits that if human populations continue to increase without constraint, they will ultimately exceed the Earth's finite resources, leading to an ecological catastrophe (Sherbinin et al., 2007). Secondly, we incorporated the hypothesis proposed by Pata and Kartal (2023) regarding the Load Capacity Curve (LCC) which suggests that the correlation between per capita income (GDP) and environmental impact can fluctuate depending on a nation's economic advancement. This theoretical framework posits that during the initial stages of development, the pursuit of higher income intensifies the demand for natural resources, exceeding the ecological carrying capacity. It acknowledges a threshold in income level beyond which further increments in per capita income trigger a reversal in the load capacity trend. Thus, we include per capita GDP as a variable in our model, both linearly and in a squared form. Our model specification includes additional factors such as the extent of FinTech integration and the impact of globalization resulting from technological advancements. We further acknowledge that natural resources can play a substantial role in understanding CO2 emissions. Based on the past studies presented by Dimnwobi et al. (2023b) and Ugwu et al. (2022), we suggest the following equation for empirical analysis:

$$\ln ELC_{i,t} = \theta_0 + \theta_1 \ln P_{i,t} + \theta_2 \ln GDP_{it} + \theta_3 \ln GDPsq_{it} + \theta_4 \ln NR_{i,t} + \theta_5 \ln GLO_{i,t} + \theta_6 \ln FinTech_{i,t} + \varepsilon_{i,t} \quad (1)$$

The equation above presents a testable STIRPAT-ELC-adjusted model, underscoring the theoretical assumptions between Ecological Load capacity (ELC) and economic factors. The variables P, GDP, GDPsq, NR, GLO, and FinTech represent population total, per capita income, the square of per capita income, the economic contribution of natural resources, the impact of international integration and globalization, and technology-driven innovations and improvements within the financial sector, respectively. The functional relationship also includes an error term, a cross-sectional country index (i), and a time index (t) that defines the years covered. The theoretical foundation load capacity curve (LCC) hypothesis as proposed by Pata and Kartal (2023) suggests a U-shaped curve, indicating that environmental degradation initially decreases and then increases as per capita income rises. This is valid if $\theta_3 < 0$ and $\theta_3 > 0$. By using a natural logarithmic form for the variables, we obtain estimates of the parameters as elasticities, which facilitates interpretation and policy formulation. Positive and statistically significant values of θ_4, θ_5 and θ_6 signify the distinct contributions of NR, GLO, and FinTech, respectively, in enhancing the ecological carrying capacity across the five North African nations.

3.2. Estimation approach

3.2.1. Cross-sectional dependency test

Appendix 4 depicts the methodological navigation of this study. To accomplish its objectives and provide novel insights, this study utilises panel estimators that are widely recognised for their robustness and reliability, even in the face of cross-sectional dependence and intercross-sectional heterogeneities. Therefore, this study investigates the cross-sectional dependency (CD) characteristics of the panel dataset by employing the CD methodologies established by Pesaran (2004). The mathematical representation of the CD can be expressed as follows:

$$CD = \sqrt{\frac{2}{B(B-B)}} \sum_{n-1}^{B-1} \sum_{m=n+1}^{B} A_{nm} B_{nm}^2 \rightarrow (B(0,1) \quad (2)$$

Where B_{nm}^2 represents the statistical measure associated with the residuals, while "A" and "B" represent the dimensions of time and cross-section, respectively.

3.2.2. Slope heterogeneity tests

The study utilizes the slope heterogeneity (SLH) technique proposed by Pesaran and Yamagata (2008) to address the issue of varying slopes. The typical SLH framework is illustrated by Equations (3) and (4):

$$\widehat{\Delta}_{SH} = (N)^{\frac{1}{2}} (2k)^{-\frac{1}{2}} \left(\frac{1}{N} \overline{S} - k \right), \quad (3)$$

$$\widehat{\Delta}_{ASH} = (N)^{\frac{1}{2}} \left(\frac{2k(T-k-1)}{T+1} \right)^{-\frac{1}{2}} \left(\frac{1}{N} \overline{S} - 2k \right) \quad (4)$$

The null and alternative hypotheses are the delta $\widehat{\Delta}_{SH}$ and modified delta $\widehat{\Delta}_{ASH}$ that is in tandem with the homogeneous and heterogeneous slope coefficients.

3.2.3. Panel unit-root tests

The research utilized various panel unit-root techniques, such as the second-generation cross-sectional IPS (Pesaran, 2007), and a modified version called truncated CIPS (CIPS-TR) that includes certain adjustments to the original CIPS test. Additionally, the study employed a third-generation panel unit-root approach developed by Karavias and Tzavalis (2016), which considers structural changes within the panel. The equation representing the CIPS is provided below.

$$\Delta Y_{it} = \omega_i + \rho_i^* Y_{i,t-1} + d_0 \overline{Y}_{t-1} + \sum_{j=0}^{p} d_{ij} \Delta \overline{Y}_{t-j} + \sum_{j=1}^{p} c_{ij} \Delta Y_{i,t-j} + \varepsilon_{it} \quad (5)$$

The symbol Δ is used to represent the difference operator. The variable of interest is denoted as Y, and the index i ranges from 1 to n, representing the countries being considered. Similarly, the index t ranges from 1 to T, representing the time periods. The stochastic error term is denoted as ε_it. The CIPS statistics are derived from Equation 5. The equation for the CIPS test can be expressed as follows.

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} CADF_i \quad (6)$$

In addition, as was previously indicated, we offer a reduced version of the CIPS statistics, called CIPS-TR. Modifications to the original CIPS test are included in the CIPS-TR, and shown below as thus:

$$CIPS - TR = \frac{1}{N} \sum_{i=1}^{N} CADF_i^* \quad (7)$$

This study employs CIPS panel unit root tests in our research to ascertain the presence of cross-sectional dependence in the data. The Westerlund (2007) cointegration test of the second generation is employed for analysing panels that possess both variation and dependency over several periods. This examination enables us to assess the presence of cointegration among the variables inside the panels, indicating the existence of a long-term association. If cointegration is seen, it becomes possible to reject the null hypothesis positing the absence of any such link.

Furthermore, the investigation employed a third-generation unit-root devised by Karavias and Tzavalis (2016) for data analysis. This strategy accounts for any modifications that may have taken place within the cohort of subjects under investigation.

$$CIPS(N,T) = \frac{\sum_{i=1}^{N} t_i(N,T)}{N} \quad (8)$$

$$X_{it} = D_{it} + \lambda_t' F_t + \lambda_t' \quad (9)$$

In the eqt 9, the variables X_{it}, D_{it}, F_t , $\lambda_t^{\prime}$and $\lambda_t^{\prime}$are utilised to denote distinct components. X_{it} is a mathematical expression that encompasses various components, including a deterministic component of D_{it}, a common component $\lambda_t^{\prime}F_t$, a polynomial trend function, a vector of r × 1 common factors, a vector of factor loadings, and the idiosyncratic error term.

3.2.4. Panel cointegration tests

To deepen our understanding of the relationships between the ecological load capacity factor and the determinants that have been identified, this study investigates the potential long-term coevolution among the panel series. To examine whether there is a lasting relationship between the variables, the study employs a method proposed by Westerlund (2007) that takes into account the presence of cross-sectional dependence (CD). The error-correction equation is formulated as follows:

$$\Delta Y_{i,t} = \mu_i^{\prime} d_t + \omega_i\left(Y_{i,t-1} - \beta_i^{\prime} X_{i,t-1}\right) + \sum_{j=1}^{k} \varnothing_{ij}\Delta Y_{i,t-j} + \sum_{j=1}^{k}\gamma_{ij}\Delta X_{i,t-j} + \varepsilon_{i,t} \tag{10}$$

The coefficient ω_i in the error-correction term represents the speed at which corrections are made towards equilibrium, Y_{it} and X_{it}represent the dependent and explanatory variables, respectively. Equation (10) yields four (4) statistics that can be derived.

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\widehat{\omega_i}}{se(\widehat{\omega_i})} \tag{11}$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\widehat{\omega_i}}{1-\sum_{j=1}^{k}\omega_{ij}} \tag{12}$$

$$P_t = \frac{\widehat{\omega}}{se(\widehat{\omega})} \tag{13}$$

$$P_a = T\widehat{\omega} \tag{14}$$

The statistics G_t and G_a examine the presence of cointegration within specific or all cross-sectional groupings, while the statisticsP_t and P_a analyze the panel as a whole for cointegration evidence.

3.2.5. Augmented mean group estimate (AMG)

The AMG estimator by Eberhardt and Teal (2010), aims to tackle the diverse tasks associated with the analysis of dynamic panel data. The issues encompass cross-sectional dependence, individual variances, and temporal changes, all of which are driven by a common underlying component. The estimation method considers latent shared factors present in sub-samples. In the first stage of the AMG method, a pooled regression model is implemented, which takes into account time-specific characteristics and variations between data points. This particular stage holds significant importance in acquiring a deeper understanding of the temporal evolution of variables and comprehending their respective contributions to the broader patterns. This initial phase is guided by the following equation:

$$Y_{it} = \rho_i + \alpha_i\Delta X_{it} + \tau_i\delta_t + \sum_{t-1}^{T}\phi_t D_t + \varepsilon_{it} \tag{15}$$

Where, α_i is introduced as the slope, δ_t as the unobserved common factor, τ_i as the heterogeneous factor loadings, D_t and ϕ_t are the year dummies and their coefficients, respectively. In the second stage of the empirical setup, the group-specific regression specification is augmented by allocating a unit coefficient to each group unit, and the group-specific parameters are averaged across the panel.

$$AMG = \frac{1}{N}\sum_{i=1}^{N}\widehat{\alpha}_i \tag{16}$$

3.2.6. Method of moments quantile regression

The primary objective of our study is to overcome a limitation in comprehensively capturing the many aspects of the conditional distribution of the ecological load capacity factor. The method of moments quantile regression (MMQR), as proposed by Machado and Silva (2019), is utilised to address this matter. This methodology allows for the effective handling of conditional effects in panel quantile models.

3.2.7. Bootstrapped simultaneous quantile regression

Additionally, we employ the Bootstrapped simultaneous quantile regression (BSQR) technique, which uses asymptotically normal sampling to remove the parametric constraint of the distribution (Efron and Tibshirani, 1994). By employing the MMQR and BSQR estimators, we can robustly examine the impact of fintech, natural resources, and globalization on the lower, median, and upper distributions of the ecological load capacity factor in North Africa. To estimate the conditional quantile $Q_y(\tau|X_{it})$ of the location-scale variant model, we modify Equation 1 based on the methodologies proposed by Machado and Silva (2019). We use a broad specification to adjust the equations.

$$Q_y(\tau|X_{it}) = (\beta_i + \delta_i qi) + X_{it}^{\prime}\beta + Z_{it}^{\prime}\gamma q(\tau) \tag{17}$$

The function $Q_y(\tau|X_{it})$ represents the quantile distribution of the dependent variableY_{it}, given the location and scale of the explanatory variable$(X_{it}^{\prime})$. $X_{it}^{\prime}$' is a vector of explanatory variables. The term $\alpha_i(\tau) = \alpha_i + \delta_i q(\tau)$ represents the impact of the distribution at τ, or the scalar coefficient of the quantile-τ fixed effect for individual i. The value of q(τ) is estimated by optimizing a specific function to find the τ-th quantile.

3.3. Data sources and variables selection

The dataset encompasses 5 North African countries, primarily selected based on the availability of annual time series data spanning from 1991 to 2022 (32 years).[4] Table A1 provides a concise summary of the definitions of the variables, data sources, fundamental descriptive statistics and correlation matrix. In this study, we utilize the concept of Ecological Load Capacity (ELC). As defined by Pata and Kartal (2023), the ELC factor represents the ratio of biocapacity to ecological footprint. A higher ELC factor signifies a more sustainable utilization of natural resources, indicating either an augmentation in biocapacity or a reduction in the country's consumption footprint. Conversely, a decrease in the ELC factor indicates unsustainable exploitation of ecological resources, revealing that the consumption footprint exceeds the natural resource capacity. This study examines the explanatory relevance of three policy variables: FinTech,[5] Total natural resources rents (% of GDP) and Overall Globalization index in North Africa, real per capita GDP and Population, total.

Appendix 1, Panel A of the study provides descriptive statistics. A higher value of the GLO, FinTech indicators suggests that globalization may have imposed stricter environmental regulations on companies,

[4] The choice of this period is motivated on the ability to accurately quantify ecological responses to various drivers of ecosystem change, such as environmental policies, economic activities, and natural phenomena. This time frame affects how well researchers can capture the complexity of ecosystem processes and how effectively they can provide core ecological data essential for developing theoretical models and informed management strategies.

[5] Constructed through principal component analysis using Fixed broadband subscriptions (per 100 people), Individuals using the Internet (% of population), Mobile cellular subscriptions (per 100 people) (refer to Table A1 in the Appendix).

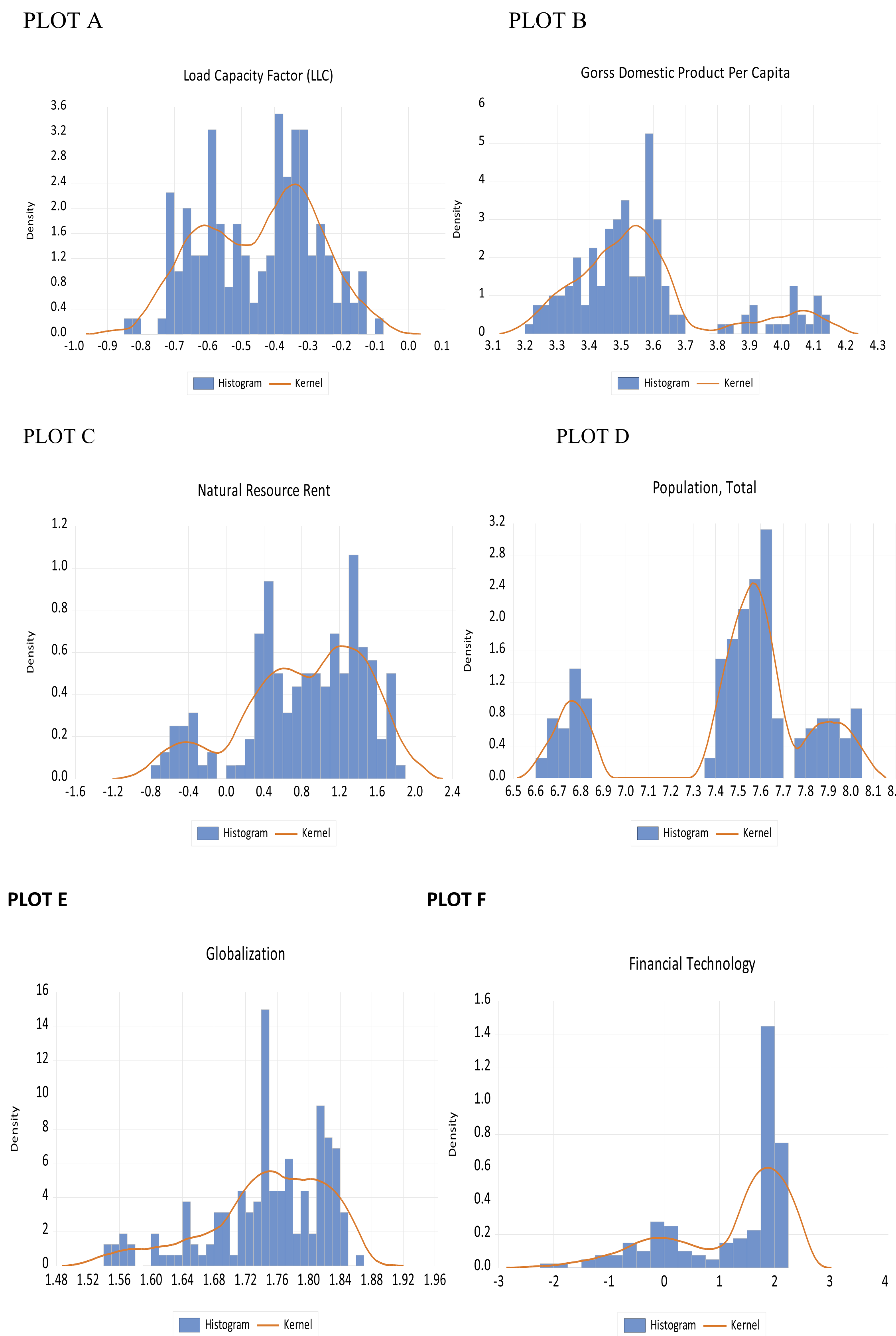


Fig. 1. Distributional Plots of the variables.

resulting in decreased pollution levels. However, it could also be interpreted that globalization has intensified, leading to a decline in environmental quality. The emergence of Fintech has significantly transformed the financial and business landscape, directing more resources towards low-carbon or environmentally friendly economic activities. Fig. 1 displays graphical plots illustrating the distribution of the study variables. To assess the strength of the linear relationship among the variables throughout the sample period, a correlation coefficient matrix is presented in Appendix 1, Panel B. It is evident that the ELC variable exhibits a stronger negative correlation with all the explanatory variables, with correlation coefficients of −0.278, −0.443, −0.466, −0.121, and −0.052.

3.4. Societal benefits of this research

One of the key benefit of evaluation the key are as folleos: Natural resource rents have emerged as a significant driver of climate change and environmental degradation. The extraction and exploitation of these resources often lead to severe ecological consequences, with the impact varying across different countries. In some cases, the diversification of natural resource rents exacerbates ecological ruin, leading to widespread environmental damage. Conversely, the adoption and increased consumption of renewable energies have been found to positively influence economic growth while enhancing environmental quality, presenting a viable pathway for sustainable development. Also, globalization, characterized by increased trade openness, has been linked to considerable effects on resource depletion. This impact is particularly pronounced in countries with medium levels of material footprint, where globalization accelerates the exhaustion of natural resources. While globalization fosters economic integration, it also poses significant challenges to environmental sustainability, as the rapid depletion of resources undermines long-term ecological balance. Finally, Fintech, with its potential to revolutionize financial systems, offers promising avenues for promoting green finance and green investments, thereby contributing to environmental sustainability. However, the influence of Fintech is not without complexities. While it has been shown to reduce mineral resource rent, this effect is not uniform across different economic contexts. Moreover, Fintech's impact on GDP is mixed, with evidence suggesting potential systemic risks that could negatively affect economic stability. Thus, while Fintech holds promise for supporting sustainability, its broader economic implications warrant careful consideration.

4. Empirical findings and discussion

4.1. Initial assessment, unit root, and cointegration analyses

Appendix 2 presents tests for normality results which indicate that the assumption of normality in the distribution of the underlying variables' series is rejected for the group of North African economies during the sample period. Additionally, Appendix.3 Panel A shows the results of the cross-sectional dependence (CD) test conducted by Pesaran (2004), indicating that the assumption of no CD is rejected for the underlying variables. Therefore, the data series for these variables exhibits cross-sectional dependence.

Appendix 3, Panel B also presents the results of the test conducted by Pesaran and Yamagata (2008) under the assumption that the slope coefficients are homogeneous. The delta statistics, along with the adjusted version, suggest that this assumption is rejected, implying that the slope coefficients of the model specifications exhibit heterogeneity. Furthermore, Appendix 4 confirms that there are no concerns about multicollinearity in the model specifications based on the Variance Inflation Factor test.

Consequently, cross-sectionally augmented unit root tests are performed. The study employs various panel unit-root procedures, including CD-adjusted (Second-generation) panel unit root tests and Karavias and Tzavalis (2016), to assess the order of integration of the panel series and to identify possible structural breaks within the panel series. The results indicate that the variables are stationary in both level and first difference form, indicating that they are integrated of order 1 (I (1)).

Based on the model specifications in Equation (1), cointegration tests are conducted. The results, as summarized in Table 2, reject the null hypothesis of no cointegration among the variables for both the panel model specifications (Pt and Pa statistics) and the cross-sectional units (Gt and Ga statistics). Thus, the presence of a long-run relationship is confirmed in all the fitted models, and the parameter estimates are computed using the AMG, MMQR, and BSQR estimators, which allow for both homogeneity and heterogeneity in the slope coefficients. Therefore, the parameter estimates are robust and reliable for making policy decisions

4.2. Results from panel regression techniques

Results obtained from panel regression techniques Table 3 displays both the overall effects estimated using the AMG approach, as well as country-specific effects, on the ecological load capacity in selected African countries. The AMG estimates focus on analyzing the impact of natural resource rent, globalization, and Fintech on ecological load capacity (ELC) across the entire panel time series. On the other hand, the

Table 2
Panel cointegration outcomes.

Statistic	Value Z	value	P-value	Robust P-value
Gt	−3.432***	1.388	0.000	0.000
Ga	−9.82***	1.822	0.000	0.000
Pt	−6.009***	0.231	0.000	0.000
Pa	−8.51***	1.194	0.000	0.000

** if $p < 0.05$
*if $p < 0.1$
*** if $p < 0.01$

Table 1
Panel unit-root estimates.

Series	CD-adjusted (Second-generation) panel unit root tests				Karavias and Tzavalis, (2016)	
	CIPS (level)	ΔCIPS	TCIPS (level)	ΔTCIPS	MIN Z-STAT	BREAK POINT
P	−2.660**	−4.617***	−2.660	−4.617***	−17.618***	2021
GDP	−2.592**	−5.538***	−2.592	−4.756***	−15.426***	2021
GDPSQ	−2.886**	−5.170***	−3.200	−5.208***	−14.843***	2021
NR	−3.521**	−5.873***	−2.542	−4.916***	−7.685***	2021
GLO	−3.200**	−5.425***	−2.860	−4.851***	−17.509***	1992
FinTech	−1.196	−3.520***	−1.196	−3.520***	−16.280***	2007
LLC	−2.542***	−6.042***	−3.521	−5.540***	17.683***	2021

*if $p < 0.1$
*** if $p < 0.01$
** if $p < 0.05$

Table 3
Regression estimates for AMG Pooled and Country Specific.

	1	Country Specific 2 3 4 5 6				
VARIABLES	AMG POOLED	Algeria	Egypt	Libya	Morocco	Tunisia
P	−0.532**	0.735**	−0.115**	0.515**	−1.328**	−2.468**
	(0.602)	(0.193)	(0.446)	(0.553)	(1.026)	(4.687)
GDP	13.57	45.939	5.816	2.542	4.865	8.693
	(8.152)	(16.240)	(11.497)	(4.509)	(12.698)	(13.950)
GDPSQ	−1.862	6.515	−0.741	−0.302	−0.440	−1.311
	(1.176)	(2.293)	(1.619)	(0.576)	(1.901)	(2.013)
NR	−0.0238**	−0.074**	−0.025**	−0.177**	0.004**	0.006**
	(0.042)	(0.061)	(0.046)	(0.051)	(0.019)	(0.168)
GLO	−0.537**	−0.152**	−1.381**	−1.156**	−1.332**	1.033**
	(0.483)	(0.340)	(0.482)	(0.542)	(0.474)	(1.152)
FinTech	0.252	0.009	0.065	0.052	0.028	1.106
	(0.214)	(0.019)	(0.039)	(0.033)	(0.031)	(0.871)
Constant	−20.22	87.041	−8.266	−6.957	0.810	0.364
	(16.810)	(28.490)	(21.841)	(7.779)	(26.890)	(26.662)
Observations	160					

*** if $p < 0.01$
* if $p < 0$.
** if $p < 0.05$

estimates from the country-specific analysis provide insights into how these explanatory variables affect ELC in individual countries. Column 1 of the AMG regression explains the average effect of the explanatory variables, ensuring the robustness of estimates to various forms of cross-sectional dependence. Columns 2–6 present estimates derived from the AMG approach for individual countries, aiming to identify differences in the effects of explanatory variables among the sampled countries.

The estimates provided by the AMG indicate that population growth, natural resource rent, and globalization have a significant negative (degrading environmental) impact on ecological load capacity factors in North African countries. Specifically, the estimates demonstrate that a change in population growth, natural resource rent, and globalization leads to a decrease in ecological load capacity factors by 0.532 %, 0.0238 %, and 0.537 %, respectively, in the long term. Based on these findings, it is evident that these three factors pose a threat to environmental sustainability in North Africa. Similar conclusions are drawn from country-specific regression findings [2–6], except for Morocco and Tunisia, where natural resource rent has a positive and mitigating effect on ecological load capacity, and Tunisia, where globalization enhances environmental quality. These results align with previous studies conducted by Li et al. (2022), Jahanger et al. (2022), Agboola et al. (2021), and Hossain et al. (2022) in the Arctic region, across 73 developing countries, Saudi Arabia, India, Awan et al. (2020) in the MENA region, Onifade et al. (2021) in E7 economies, and Erdoğan et al., (2020) in SSA countries. Consequently, policymakers should develop strategies to redirect population growth, interconnectedness, and resource extraction towards environmentally friendly practices. Additionally, raising awareness among the population about the negative consequences of compromised environmental quality and implementing effective birth control measures could help alleviate the observed ecological deficits. It is important to emphasize that these estimates corroborate and validate the first and second hypotheses proposed in the existing literature.

Additional evidence regarding the environmental consequences of affluence, as represented by economic growth (GDP per capita), is examined using the quadratic specification of the LCC hypothesis. The results, presented in columns [1–6], indicate that the coefficients for both variable A and the quadratic term (ASQ) are statistically insignificant. This suggests that the LCC hypothesis does not adequately explain the process of mitigating ecological load capacity for the selected group of five North African economies. In relation to this panel, FinTech has a positive but statistically insignificant impact on ecological load capacity. While this result aligns with theoretical expectations, it lacks statistical significance at the conventional level. Therefore, based on these findings, it can be inferred that FinTech has the potential to mitigate environmental degradation by reducing intensity of energy consumption in productive activities. These findings are consistent with those of Udeagha and Ngepah (2023) and Tao et al (2021). However, our study indicates a relatively weaker impact on environmental sustainability compared to previous research, which found a stronger influence. The divergence in results could be attributed to differences in methodology and variable selection. To gain further insights and establish a more conclusive stance on the existing literature and hypothesis three, we employed additional econometric tools such as MMQR and BSQR for further investigation and robust verification.

4.3. Robust check

Table 4 presents the outcomes of the panel quantile regression model, which showcases the panel quantile results for the conditional ecological load capacity at different percentiles (25th, 50th, and 75th). The table displays the findings of both the BSQR estimator on the right side and the MMQR estimator on the left side. Beginning with the main policy variables and the model's reported statistical significance in the study, the impact of income level is both mixed and statistically significant across the entire quantile distribution for both MMQR and BSQR. This demonstrates the complex nature of the developmental path in North Africa. By utilizing MMQR and referring to Fig. 2, the parameter estimates provide evidence that contradicts the LLC hypothesis for the selected economies. In other words, the relationship between per capita GDP (A) and ecological load capacity does not follow a U-shaped pattern, but rather an inverted U-shaped pattern observed only at the 25th and 50th quantiles respectively. This implies that on average, a 1 % change in the income level (A) leads to an increase in ecological load capacity from 2.111 % at the 25th quantile to 1.319 % at the 50th quantile. This suggests that countries at the lower quantiles of ecological load capacity distribution gradually shift towards environmentally friendly alternative economic activities, thereby reducing the degradation of ecological load capacity. This result confirms that income is a significant driver of environmental pressures. A higher income level resulting from the expansion of economic activities for energy-intensive goods and services leads to both a lower level and an acceleration of environmentally friendly practices. This aligns with the technological effect argument of the environmental Kuznets curve (EKC) hypothesis, which is supported by similar findings in studies by Dimnwobi et al. (2023a), and Dimnwobi et al. (2023b).

Regarding the impact of natural resource rents on the ecological load

Table 4
Panel quantile regression estimation results (MMQR and BSQR).

	MMQR					BSQR		
	1	2	3	4	5	6	7	8
VARIABLES	location	scale	qtile_25	qtile_50	qtile_75	bsqr_25	bsqr_50	bsqr_75
P	−0.438**	0.0794	−0.497***	−0.442***	−0.368*	−0.101	−0.234	−0.27
	(0.170)	(0.117)	(0.183)	(0.168)	(0.205)	(0.092)	(0.173)	(0.171)
GDP	1.257*	−1.150***	2.111***	1.319*	0.238	−4.537*	−2.904	1.899
	(0.714)	(0.401)	(0.685)	(0.710)	(0.907)	(2.588)	(4.709)	(3.065)
GDPSQ	−0.169*	0.150***	−0.280***	−0.177*	−0.0361	0.53	0.289	−0.330
	(0.092)	(0.052)	(0.087)	(0.092)	(0.119)	(0.350)	(0.631)	(0.427)
NR	0.0318**	−0.00259	−0.0337**	−0.0320**	−0.0295*	−0.0664*	−0.0797*	−0.158***
	(0.015)	(0.010)	(0.017)	(0.015)	(0.017)	(0.036)	(0.054)	(0.034)
GLO	−1.480***	0.0973	−1.552***	−1.485***	−1.394***	−1.714***	−1.278**	−1.203***
	(0.191)	(0.117)	(0.231)	(0.192)	(0.191)	(0.440)	(0.556)	(0.431)
FinTech	0.0147	0.00172	0.0134	0.0146	0.0162	0.0917***	0.107***	0.0813***
	(0.011)	(0.007)	(0.012)	(0.011)	(0.014)	(0.023)	(0.039)	(0.025)
Constant	3.033*	1.464	1.947	2.955*	4.330*	12.58**	10.13	1.236
	(1.722)	(0.988)	(1.606)	(1.715)	(2.230)	(4.984)	(8.696)	(5.060)
Observations	160	160	160	160	160	160	160	160

*** if $p < 0.01$
** if $p < 0.05$
* if $p < 0.1$

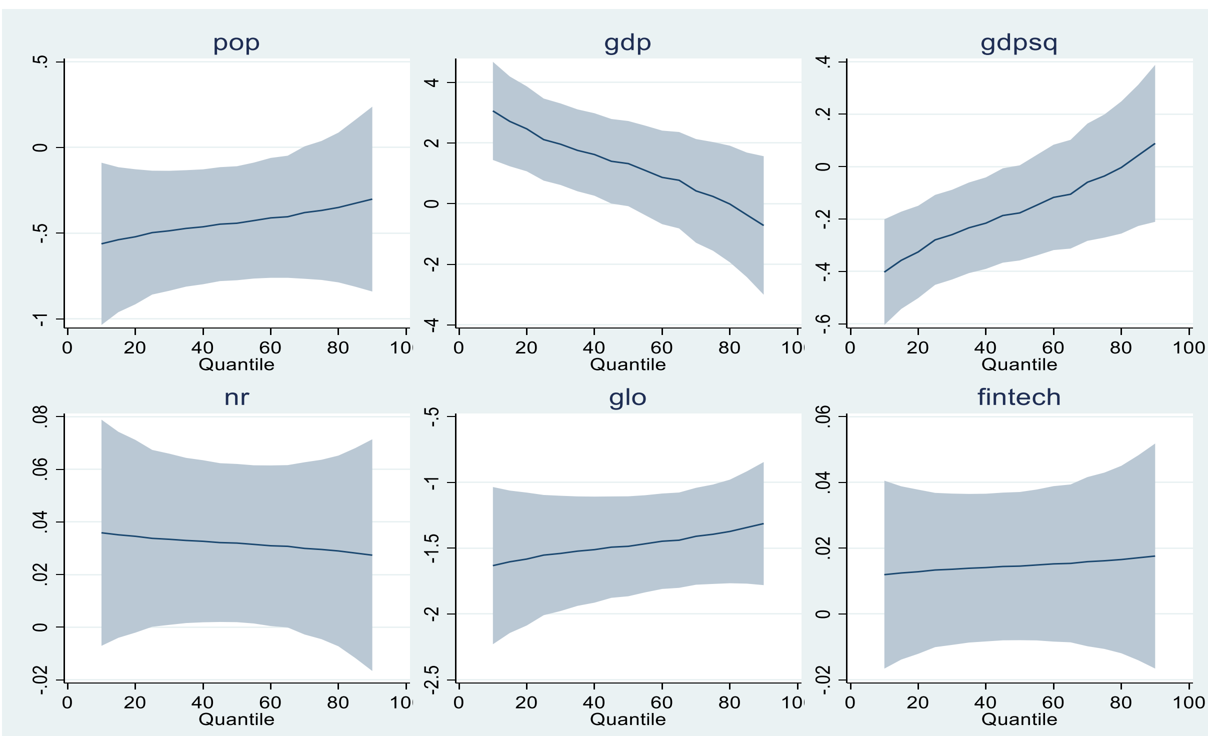


Fig. 2. Quantile plots.

capacity factor in North Africa, the study finds that both MMQR and BSQR exhibit a consistent negative and significant relationship across different quantiles. This finding aligns with the AMG parameter estimates in Table 1, model [1–4]. The estimates indicate that a 1 % change in natural resource rents leads to a decrease in ecological load capacity factors by 0.0337–0.0295 % for MMQR and 0.0664–0.158 % for BSQR. Furthermore, the parameter estimates for the upper quantile sample suggest that natural resource rents have a more pronounced negative environmental impact in these countries compared to the lower quantiles. This supports the findings of Usman et al. (2022), Luo and Mabrouk (2022), and Afshan and Yaqoob (2022), reinforcing hypothesis 1. Like the resource curse hypothesis, the outcome demonstrates how the abundance of natural resources in these countries has a detrimental impact on environmental sustainability. This indicates that the advantages benefit from extracting and processing raw materials are predominantly enjoyed by a privileged few who hold positions of power and are unable to allocate these profits towards environmentally friendly economic endeavors in the five North African countries. This discovery aligns with earlier assertions that revenue generated from natural resources is frequently invested in activities that worsen environmental sustainability.

Regarding the impact of the globalization index, both the MMQR and BSQR estimates show a statistically significant negative effect. The estimates indicate that ecological load capacity factors deteriorate by 1.552–1.394 % for MMQR and 1.714–1.203 % for BSQR, given a one-unit change in globalization in the selected countries in North Africa.

These findings support the pollution haven hypothesis, which suggests that globalization leads to inadequate environmental regulations in developing nations, attracting foreign industries and resulting in increased pollution. This pollution can manifest in various ways, such as habitat degradation, resource competition, or a decline in biodiversity, leading to ecological imbalances and integrity issues. Ultimately, this can exceed the load capacity factor, negatively impacting the health and functioning of ecosystems. Similar research repositories include Etokakpan et al. (2020), Sabir and Gorus (2019), Murshed et al. (2022), Wen et al. (2021), Wang et al. (2020), and Hussain and Zhou (2022).

Interestingly, our investigation, employing sophisticated simulation methods like BSQR, has produced an intriguing result. Our research revealed that in the North African region, fintech, has a statistically significant and favourable effect on environmental sustainability. More specifically, for the 25th, 50th, and 75th percentiles, an increase of 1 % in fintech is linked to an improvement in ecological load capacity of 0.0917 %, 0.107 %, and 0.0813 %, respectively. This implies that by utilizing big data and machine learning to motivate eco-friendly behaviour among economic agents and small enterprises, fintech plays a critical role in promoting environmentally friendly practices and investments in North Africa. Local FinTech companies are hard at work offering substitute "green financial systems" that rely on technology breakthroughs to lower load capacity and boost energy efficiency, thus maintaining environmental integrity. These results are consistent with earlier research on low-carbon transition economies by Tao et al. (2021) and the BRICS countries by Udeagha and Ngepah (2023), which also showed the beneficial effects of FinTech on environmental sustainability. Our results, however, run counter to those of Lisha et al., (2022), who claimed that FinTech accelerated environmental degradation in the BRICS countries. They contended that a significant portion of the energy used to mine different types of FinTech comes from non-renewable resources, which has detrimental consequences on the environment and reduces ecological load capacity, among other things. In a larger sense, the divergent perspectives of the FinTech-environment connection imply that it may be linked to rising death rates, global warming, and environmental deterioration. However, our research supports the third hypothesis, according to which FinTech significantly contributes to environmental deterioration in North Africa.

4.4. Causality results

To strengthen our findings and offer policy guidance to navigate the path towards environmental sustainability, we utilize the Half-Panel Jackknife (HPJ) Wald-type test, which was developed by Juodis et al. (2021). This test enhances the reliability of our empirical results and demonstrates better performance in terms of size and power compared to similar methods found in the literature. It is capable of estimating panel data models that are multivariate and heterogeneous. The HPJ Wald test employs the bias-corrected pooled estimator to assess the impact of selected covariates on the equation. It also utilizes cross-sectional heteroskedasticity-robust standard errors. The results are presented in Table 5. In specifications (1) of the analysis, we investigate whether P, GDP, GDPsq, NR GLO, and FinTech have a Granger causality relationship with ELC. The HPJ Wald statistic is statistically significant in these specifications, rejecting the null hypothesis that the covariates do not Granger-cause ECL in the entire sample. Additionally, the regression output of the bias-corrected pooled estimator in Panel B reveals that the test outcome of the multivariate equation is significantly influenced by past values of P, GDP, GDPsq, NR, and FinTech. There is evidence of bidirectional causality between ELC and GDP, GDPsq, and FinTech (as indicated in columns 3, 4, and 7). Another noteworthy finding is the unidirectional positive relationship between GLO and ELC (as observed in column 1).

5. Conclusion and policy remarks and limitations

5.1. Conclusion

The rapid growth of global economic interconnectedness enables the movement of goods and services from high-energy consumption areas to those with lower energy intensity. In this research, we identified five countries in North Africa that heavily rely on FinTech, natural resources, and globalization from 1991 to 2022 (a span of 32 years). To understand the impact of FinTech, natural resources, and globalization on ecological load capacity, we used an extended LLC equation, considering potential differences in distribution and the direction of causality. To ensure robust statistical analysis, we confirmed cross-sectional dependency in the data and employed a second third-generation panel unit root test and cointegration test. Once cointegration was confirmed, we examined the

Table 5
JKS multivariate non-causality test.

Equation	1 LCF	2 P	3 GDP	4 GDPSQ	5 NR	6 GLO	7 FinTech
Panel A: Non-causality test							
	83.309***	13.2611***	281.784***	310.252***	365.774***	87.495***	52.732***
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Panel B: -Panel Jackknife estimates of Selected covariates							
L.P	0.283		−0.119	−0.566	−3.536***	−0.370***	−0.627
	(0.262)		(0.274)	(2.227)	(1.093)	(0.057)	(1.152)
L.GDP	−6.009***	−0.244		273.3***	15.79***	1.056***	−7.473
	(2.040)	(0.244)		(24.970)	(0.964)	(0.285)	(6.426)
L.GDPSQ	0.767***	0.0328	−4.432***		−1.832***	−0.134***	1.107
	(0.259)	(0.031)	(0.406)		(0.123)	(0.036)	(0.799)
L.NR	0.0352***	0.00300***	0.0159***	0.105***		0.00012	0.0513
	(0.005)	(0.001)	(0.003)	(0.024)		(0.005)	(0.048)
L.GLO	−0.678***	−0.0744***	0.518***	4.646***	−1.221***		−0.799
	(0.415)	(0.027)	(0.188)	(1.426)	(0.422)		(1.144)
L. FinTech	0.0386***	−0.000617	0.0484***	0.334***	0.273***	0.0283***	
	(0.003)	(0.001)	(0.005)	(0.039)	(0.051)	(0.005)	
L.LCF		−0.0155	0.338**	2.634**	0.279	0.0133	0.421**
		(0.010)	(0.148)	(1.133)	(0.391)	(0.022)	(0.203)
No of ID	5	5	5	5	5	5	5

Selected covariates do not Granger-cause;: H_0 is violated; Standard errors in ()
* $p<0.1$
*** $p<0.01$
** $p<0.05$

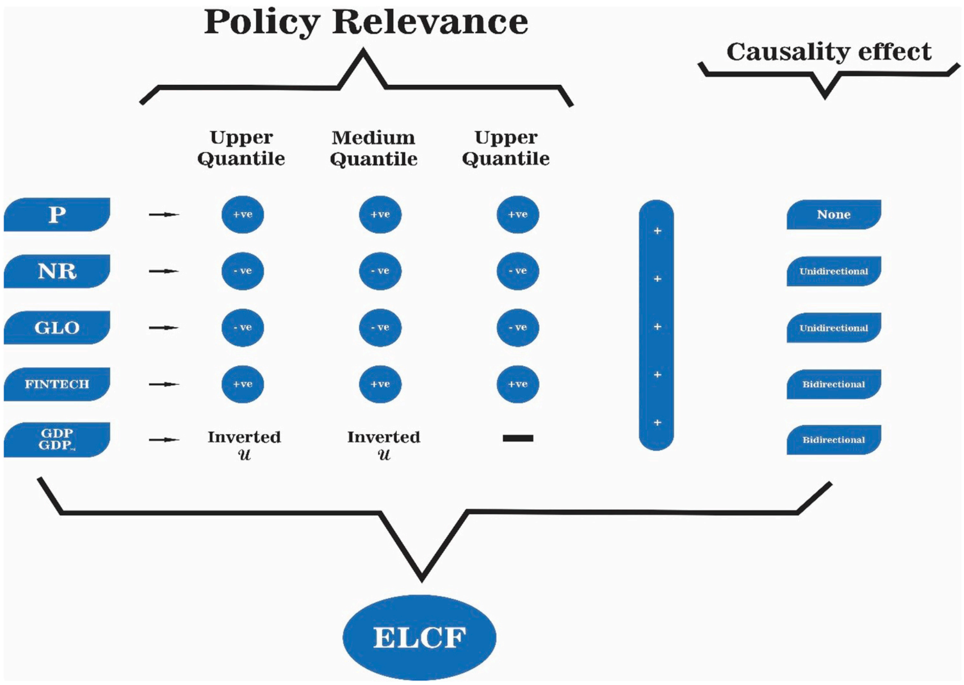


Fig. 3. Graphical representation of empirical fininding*s*.

role of the enlisted variables on ecological load capacity using AMG and its country-specific analyses. Additionally, we conducted further investigations using novel quantile variants and the Half-Panel Jackknife (HPJ) Wald-type test to test for causality. The key findings are as follows (see Fig. 3 for detail illustration):

- The relationship between per capita GDP and ecological load capacity does not follow a U-shaped pattern, but rather an inverted U-shaped pattern at the 25th and 50th quantiles.
- Natural resource rents and globalization have a negative and significant relationship with the ecological load capacity factor in North Africa.
- The abundance of natural resources and globalization in these countries have a detrimental impact on environmental sustainability.
- Fintech has a statistically significant and favourable effect on environmental sustainability.
- Causality tests reveal that per capita GDP, GDP squared, natural resource rents, globalization, and FinTech have a Granger causality relationship with ecological load capacity.
- There is a bidirectional causality between ecological load capacity and per capita GDP, GDP squared, and Fintech.
- There is a unidirectional positive relationship between globalization and ecological load capacity.

5.2. Policy remark

Addressing the outcomes of our research, which highlight the adverse effects of natural resources on ecological quality in North Africa, a pivotal and intricate policy suggestion involves the implementation of strict resource management strategies to mitigate ecological decay. Decision-makers in these economies have to prioritize a sustainable method of extracting resources and imposing stringent ecological standards to reduce their environmental effects. The utilization of economic inducements for the uptake of eco-friendly devices in the natural resource sector is also very essential. Policymakers in these economies can also consider funding ecological restoration initiatives to assist in reverting the harm triggered by harnessing resources. Additionally, increasing the awareness level of the public and encouraging community engagement in ecological protection is also critical for the sustainable management of natural resources. Moreover, our research emphasizes the vital significance of broadening revenue-generating pursuits to diminish the region's dependence on industries with high resource intensity. Decision-makers should explore investments in unconventional and eco-friendly sectors, such as renewable energy initiatives or eco-tourism (Dimnwobi et al., 2022b, Dimnwobi et al., 2023c). This deliberate transition not only alleviates the ecological consequences linked to conventional resource extraction but also encourages a more equitable and environmentally conscious economy, nurturing the ability to withstand economic disruptions while safeguarding ecosystems (Onuoha et al., 2023a, 2023b)

In addressing the detrimental ecological impacts of globalization in North Africa, decision-makers should prioritize the creation and implementation of eco-conscious regulations. This entails formulating explicit guidelines for both domestic and foreign industries, mandating adherence to eco-conscious methods. Concurrently, governments have the option to introduce incentives like subsidies or tax breaks for enterprises embracing and showcasing a commitment to environmentally conscious methods. By incorporating these criteria into trade agreements and promoting green initiatives, policymakers can cultivate a more conscientious approach to economic progress, aiming to minimize ecological damage and encourage sustainable practices over the long term.

To leverage the beneficial influence of Fintech on the ecological quality in North African economies, decision-makers should encourage and facilitate collaboration within the financial technology sector for the creation and adoption of eco-friendly solutions. This goal can be achieved by providing subsidies, tax incentives, or alternative financial benefits to companies actively involved in the development of eco-friendly Fintech products and services. Moreover, nurturing partnerships among Fintech companies, research institutions, environmental groups, and government agencies can bolster the creation of inventive initiatives aimed at addressing distinct ecological issues. Through the establishment of a collaborative environment, decision-makers can propel the expansion of eco-friendly Fintech projects, thereby magnifying their beneficial impact on environmental sustainability.

5.3. Theoretical contribution

This study makes a significant theoretical contribution by identifying a inverted U-shaped relationship between per capita GDP and ecological load capacity, offering new insights into the intricate dynamics between economic growth and environmental sustainability. This finding challengesU-shaped assumptions and highlights how different stages of economic development influence environmental stress, ultimately informing more compex approaches to sustainable growth. Moreover, the study reveals a negative association between natural resource rents and globalization with ecological load capacity, deepening our understanding of how these factors can detrimentally impact environmental sustainability. This insight underscores the importance of careful resource management and the potential risks associated with globalization on ecological systems. In addition, the research highlights the positive impact of Fintech on environmental sustainability, providing valuable perspectives on the role of financial technologies in addressing environmental challenges. This contribution suggests that Fintech can be a powerful tool in promoting sustainability, offering pathways to mitigate environmental degradation through innovative financial solutions.

5.4. Limitations and future directions

The current research, akin to other studies, is not devoid of limitations. Primarily, since the study was conducted in North African economies, the findings might not be universally applicable to other geographical regions. Subsequent research endeavours could explore the ramifications of these interactions in diverse world regions or within a different context. Secondly, the investigation exclusively examines Fintech, natural resources, globalization, population, and economic growth as catalysts for environmental sustainability. Future research should encompass additional factors influencing environmental sustainability, such as technological innovation, structural change, and other pertinent variables. Finally, within our analysis, we utilized the load capacity factor as a proxy for environmental quality. Subsequent studies should compare the load capacity factor with alternative ecological quality metrics to offer additional insights into how diverse metrics capture and portray ecological quality, acknowledging the multidimensional aspects of sustainability.

Funding

The authors declare that no financial support was received for the research and publication of this manuscript.

Author contributions

1. **Kingsley I. Okere**: Conceived and designed the study; led the data analysis and interpretation; wrote the manuscript; and reviewed and approved the final version of the manuscript.
2. **Stephen Kelechi Dimnwobi**: Contributed to the design of the study; assisted with data collection and analysis; provided critical revisions of the manuscript; and reviewed and approved the final version of the manuscript.
3. **Ismail O. Fasanya**: Assisted with data collection and analysis; contributed to the interpretation of results; provided feedback on the manuscript; and reviewed and approved the final version of the manuscript.

Ethical statement

This research was conducted in accordance with ethical standards. The study did not involve human or animal subjects. All procedures and practices adhered to the relevant ethical guidelines and regulations.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest to disclose in relation to this manuscript.

Appendix: Results from Preliminary Tests

Appendix 1
Descriptive Statistics and Correlation matrix

Panel A: Descriptive Statistics						
Definition/ Measurement		Variables	Mean	Maximum	Minimum	Std. Dev.
Population, total		P	39228699	110000000	4300000	26297615
GDP per capita in constant 2015 US dollars		GDP	4257	13729	1668	2853
Total natural resources rents (% of GDP)		NR	14.56	66.06	0.195	15.767
Overall Globalization index		GLO	56.65	73.35	35.00	9.171
Fixed broadband subscriptions (per 100 people).						
Individuals using the Internet (% of population),						
Mobile cellular subscriptions(per 100 people)						
Principal component analysis of the above three variables		FinTech	56.696	168.492	0.009	47.969
Ecological Load Capacity Factor = Biocapacity divided by Ecological Footprint		ELC	0.386	0.812	0.147	0.145
Panel B: Correlation Matrix						
	POP	GDP	NR	GLO	FinTech	ELC
P	1.000					
GDP	−0.498	1.000				
NR	−0.484	0.824	1.000			
GLO	0.609	−0.270	−0.492	1.000		
FinTech	0.129	0.098	−0.176	0.697	1.000	
ELC	−0.278	−0.443	−0.466	−0.121	−0.052	1.000

Overall globalization index KOF, complied by Gygli et al. (2019) https://kof.ethz.ch/en/forecas ts-andindicators/indicators/kofglobalisation-index.htm

Appendix.2
Tests for normality.

Variable	Obs	Pr(skewness)	Pr(kurtosis)	Adj chi2(2)	Prob>chi2
Skewness and kurtosis tests for normality					
P	160	0.000	0.635	14.55	0.001
GDP	160	0.000	0.067	22.38	0.000
GDPSQ	160	0.000	0.029	26.53	0.000
NR	160	0.002	0.333	9.15	0.010
GLO	160	0.000	0.522	14.01	0.001
FinTech	160	0.000	0.9726	19.11	0.0001
ELC	160	0.464	0.000	16.84	0.000
		W	V	z	Prob>z
Shapiro–Wilk W test for normal data					
P	160	0.853	18.039	6.580	0.000
GDP	160	0.880	14.815	6.132	0.000
GDPSQ	160	0.859	17.394	6.497	0.000
NR	160	0.943	6.953	4.411	0.000
GLO	160	0.927	9.028	5.005	0.000
FinTech	160	0.80435	24.062	7.235	0.000
ELC	160	0.968	3.945	3.122	0.001

Note: $^{***}p < 0.01$ signifies that the normality assumption is rejected for the distribution at the 1 % significance level.

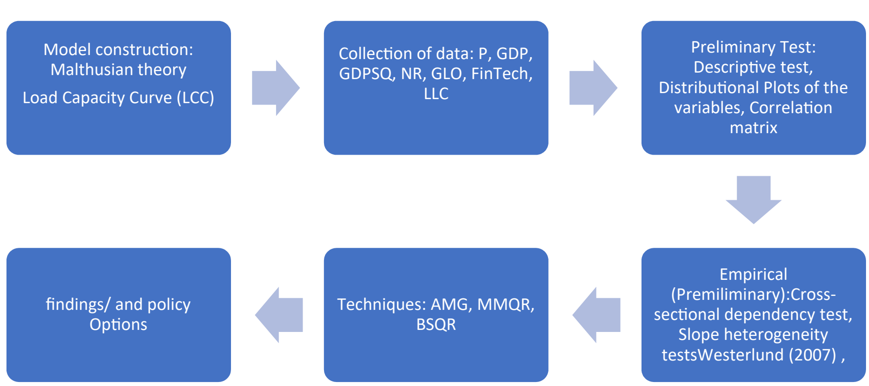
Appendix.3
Estimates of CD and Pesaran and Yamagata (2008) slope heterogeneity tests (SH).

Variable	CD-test	p-value	average joint T	mean ρ	mean abs(ρ)
Panel A: CD test					
P	17.505	0.000	32	0.980	0.980
GDP	14.564	0.000	32	0.810	0.810
GDPSQ	14.453	0.000	32	0.810	0.810
NR	5.262	0.000	32	0.290	0.400
GLO	16.754	0.000	32	0.940	0.940
FinTech	16.701	0.000	32	0.93	0.93
LCF	13.722	0.000	32	0.770	0.770
	SH	p value			
Panel B: SH test					
Delta	3.570	0.000			
Adj.	4.122	0.000			

significance levels for correlation across panel groups: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Appendix.4
variance Inflation Factor

variable	VIF	1/VIF
GDP	1.363	0.734
GDPSQ	1.331	0.751
GLO	2.211	0.452
P	1.060	0.943
FinTech	2.050	0.488
NR	1.050	0.952
Mean VIF	9.065	



Appendix 4. Graphical methodology.

References

Adebayo, T.S., Ullah, S., Kartal, M.T., Ali, K., Pata, U.K., Ağa, M., 2023. Endorsing sustainable development in BRICS: the role of technological innovation, renewable energy consumption, and natural resources in limiting carbon emission. Sci. Total Environ. 859, 160181 https://doi.org/10.1016/j.scitotenv.2022.160181.

Adjei, M., Song, H., Cai, X., Nketiah, E., Obuobi, B., Adu-Gyamfi, G., 2022. Globalization and economic complexity in the implementation of carbon neutrality in Africa's largest economies. Sustain. Energy Technol. Assess. 52, 102347 https://doi.org/10.1016/j.seta.2022.102347.

Adun, H., Ishaku, H.P., Ogungbemi, A.T., 2022. Towards Renewable energy targets for the Middle East and North African region: a decarbonization assessment of energy-water nexus. J. Clean. Prod. 374, 133944 https://doi.org/10.1016/j.jclepro.2022.133944.

Afshan, S., Yaqoob, T., 2022. The potency of eco-innovation, natural resource and financial development on ecological footprint: a quantile-ARDL-based evidence from China. Environ. Sci. Pollut. Res. 29, 50675–50685. https://doi.org/10.1007/s11356-022-19471-w.

Agboola, M.O., Bekun, F.V., Joshua, U., 2021. Pathway to environmental sustainability: nexus between economic growth, energy consumption, CO2 emission, oil rent and total natural resources rent in Saudi Arabia. Resour. Policy 74, 102380. https://doi.org/10.1016/j.resourpol.2021.102380.

Ahmed, Z., Cary, M., Le, H.P., 2020. Accounting asymmetries in the long-run nexus between globalization and environmental sustainability in the United States: an aggregated and disaggregated investigation. Environ. Impact Assess. Rev. 86, 106511 https://doi.org/10.1016/j.eiar.2020.106511.

Aladejare, S.A., 2022. Natural resource rents, globalisation and environmental degradation: new insight from 5 richest African economies. Resour. Policy 78, 102909. https://doi.org/10.1016/j.resourpol.2022.102909.

Ali, E.B., Opoku-Mensah, E., Ofori, E.K., Agbozo, E., 2023a. Load capacity factor and carbon emissions: assessing environmental quality among MINT nations through technology, debt, and green energy. J. Clean. Prod. 428, 139282 https://doi.org/10.1016/j.jclepro.2023.139282.

Ali, E.B., Shayanmehr, S., Radmehr, R., Amfo, B., Awuni, J.A., Gyamfi, B.A., Agbozo, E., 2023b. Exploring the impact of economic growth on environmental pollution in South American countries: how does renewable energy and globalization matter? Environ. Sci. Pollut. Res. 30, 15505–15522. https://doi.org/10.1007/s11356-022-23177-4.

Alvarado, R., Tillaguango, B., Cuesta, L., Pinzon, S., Alvarado-Lopez, M.R., Işık, C., Dagar, V., 2022. Biocapacity convergence clubs in Latin America: an analysis of their determining factors using quantile regressions. Environ. Sci. Pollut. Res. 29, 66605–66621. https://doi.org/10.1007/s11356-022-20567-6.

Attig-Bahar, F., Ritschel, U., Akari, P., Abdeljelil, I., Amairi, M., 2021. Wind energy deployment in Tunisia: Status, Drivers, Barriers And Research Gaps - A Comprehensive Review. Energy Rep. 7, 7374–7389. https://doi.org/10.1016/j.egyr.2021.10.087.

Avcı, P., Sarıgül, S.S., Karataşer, B., Cetin, M., Aslan, A., 2024. Analysis of the relationship between tourism, green technological innovation and environmental quality in the top 15 most visited countries: evidence from method of moments quantile regression. Clean. Technol. Environ. Policy 26, 2337–2355. https://doi.org/10.1007/s10098-023-02708-8.

Awan, A.M., Azam, M., Saeed, I.U., Bakhtyar, B., 2020. Does globalization and financial sector development affect environmental quality? A panel data investigation for the Middle East and North African countries. Environ. Sci. Pollut. Res. 27, 45405–45418. https://doi.org/10.1007/s11356-020-10445-4.

Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., Farhani, S., 2018. How economic growth, renewable electricity and natural resources contribute to CO2 emissions? Energy Policy 113, 356–367. https://doi.org/10.1016/j.enpol.2017.10.050.

Çetin, M., Aslan, A., Sarıgül, S.S., 2022. Analysis of the dynamics of environmental degradation for 18 upper middle-income countries: the role of financial development. Environ. Sci. Pollut. Res. 29, 64647–64664. https://doi.org/10.1007/s11356-022-20290-2.

Çetin, M., Sarıgül, S.S., Topcu, B.A., Alvarado, R., Karataser, B., 2023. Does globalization mitigate environmental degradation in selected emerging economies? assessment of the role of financial development, economic growth, renewable energy consumption and urbanization. Environ. Sci. Pollut. Res. 30, 100340–100359. https://doi.org/10.1007/s11356-023-29467-9.

Cetin, M., Ozturk, I., Sarigul, S.S., Murshed, M., Kilavuz, E., 2024. Nexus between technological innovation and environmental pollution in selected OECD countries. Nat. Resour. Forum. https://doi.org/10.1111/1477-8947.12458.

Cheng, X., Yao, D., Qian, Y., Wang, B., Zhang, D., 2023. How does fintech influence carbon emissions: Evidence from China's prefecture-level cities. Int. Rev. Financ. Anal. 87, 102655 https://doi.org/10.1016/j.irfa.2023.102655.

Dagar, V., Dagher, L., Rao, A., Doytch, N., Kagzi, M., 2024. Economic policy uncertainty: Global energy security with diversification. Econ. Anal. Policy 82, 248–263. https://doi.org/10.1016/j.eap.2024.03.008.

Deng, Y., Dong, K., 2024. How does the coal-to-gas policy mitigate carbon emissions? The role of fintech development. Resour. Policy 89, 104605. https://doi.org/10.1016/j.resourpol.2023.104605.

Deng, S., Tiwari, S., Khan, S., Razib Hossain, M., Chen, R., 2024. Investigating the load capacity curve (LCC) hypothesis in leading emitter economies: Role of clean energy and energy security for sustainable development. Gondwana Res. 128, 283–297. https://doi.org/10.1016/j.gr.2023.10.020.

Dietz, T., Rosa, E.A., 1994. Rethinking the environmental impacts of population, affluence and technology. Hum. Ecol. Rev. 1 (2), 277–300.

Dimnwobi, S.K., Ekesiobi, C., Madichie, C.V., Asongu, S.A., 2021. Population dynamics and environmental quality in Africa. Sci. Total Environ. 797, 149172 https://doi.org/10.1016/j.scitotenv.2021.149172.

Dimnwobi, S.K., Okere, K.I., Onuoha, F.C., Ekesiobi, C., 2022a. Energy poverty, environmental degradation and agricultural productivity in Sub-Saharan Africa. Int. J. Sustain. Dev. World Ecol. 30 (4), 428–444. https://doi.org/10.1080/13504509.2022.2158957.

Dimnwobi, S.K., Madichie, C.V., Ekesiobi, C., Asongu, S.A., 2022b. Financial development and renewable energy consumption in Nigeria. Renew. Energy 192, 668–677. https://doi.org/10.1016/j.renene.2022.04.150.

Dimnwobi, S.K., Okere, K.I., Onuoha, F.C., Uzoechina, B.I., Ekesiobi, C., Nwokoye, E.S., 2023a. Energizing environmental sustainability in Sub-Saharan Africa: the role of governance quality in mitigating the environmental impact of energy poverty. Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-023-29541-2.

Dimnwobi, S.K., Okere, K.I., Azolibe, C.B., Onyenwife, K.C., 2023b. Towards a green future for Sub-Saharan Africa: Do electricity access and public debt drive environmental progress. Environ. Sci. Pollut. Res. 94960–94975. https://doi.org/10.1007/s11356-023-29058-8.

Dimnwobi, S.K., Onuoha, F.C., Uzoechina, B.I., Ekesiobi, C.S., Nwokoye, E.S., 2023c. Does public capital expenditure reduce energy poverty? Evidence from Nigeria. Int. J. Energy Sect. Manag. 17 (4), 717–738. https://doi.org/10.1108/IJESM-03-2022-0008.

Dong, Z., Zhou, Z., Ananzeh, M., Hoang, K.N., Shamansurova, Z., Luong, T.A., 2023. Exploring the asymmetric association between fintech, clean energy, climate policy, natural resource conservations and environmental quality. A post-COVID perspective from Asian countries. Resour. Policy 88, 104489. https://doi.org/10.1016/j.resourpol.2023.104489.

Du, J., Yang, X., Long, D., Xin, Y., 2024. Modelling the influence of natural resources and social globalization on load capacity factor: New insights from the ASEAN countries. Resour. Policy *91*, 104816. https://doi.org/10.1016/j.resourpol.2024.104816.

Eberhardt, M., & Teal, F. (2010). Productivity analysis in global manufacturing production. Economics Series Working Papers, vol. 515. University of Oxford, Department of Economics.

Efron, B. & Tibshirani, R.J. (1994). An introduction to the Bootstrap. https://doi.org/10.1201/9780429246593.

Erdoğan, S., Çakar, N.D., Ulucak, R., Kassouri, Y., 2020. The role of natural resources abundance and dependence in achieving environmental sustainability: Evidence from resource-based economies. Sustain. Dev. 29 (1), 143–154. https://doi.org/10.1002/sd.2137.

Etokakpan, M.U., Adedoyin, F.F., Vedat, Y., Bekun, F.V., 2020. Does globalization in Turkey induce increased energy consumption: insights into its environmental pros and cons. Environ. Sci. Pollut. Res. 27, 26125–26140. https://doi.org/10.1007/s11356-020-08714-3.

Ezenekwe, U.R., Okere, K.I., Dimnwobi, S.K., Ekesiobi, C., 2023. Balancing the scales: Does public debt and energy poverty mitigate or exacerbate ecological distortions in Nigeria? Int. Soc. Sci. J. https://doi.org/10.1111/issj.12465.

Fang, Z., Wang, T., Yang, C., 2024. Nexus among natural resources, environmental sustainability, and political risk: Testing the load capacity factor curve hypothesis. Resour. Policy 90, 104791. https://doi.org/10.1016/j.resourpol.2024.104791.

FAO (2020). Global forest resources assessment 2020. https://www.fao.org/documents/card/en/c/ca8753en.

Grossman, G., & Krueger, A. (1991) Environmental impacts of a North American free trade agreement. National Bureau of Economics Research Working Paper, No. 3194. https://doi.org/10.3386/w3914.

Guo, Y., Wang, F., Li, P., 2023. The interplay of Fintech, natural resources, globalization, and environmental sustainability in China: A BARDL investigation. Resour. Policy 88, 104476. https://doi.org/10.1016/j.resourpol.2023.104476.

Hossain, M.R., Rej, S., Awan, A., Bandyopadhyay, A., Islam, M.S., Das, N., Hossain, M.E., 2022. Natural resource dependency and environmental sustainability under N-shaped EKC: The curious case of India. Resour. Policy 80, 103150. https://doi.org/10.1016/j.resourpol.2022.103150.

Hussain, J., Zhou, K., 2022. Globalization, industrialization, and urbanization in Belt and Road Initiative countries: Implications for environmental sustainability and energy demand. Environ. Sci. Pollut. Res. 29, 80549–80567. https://doi.org/10.1007/s11356-022-21520-3.

IUCN (2023). The IUCN red list of threatened species. ⟨https://www.iucnredlist.org/⟩.

Jahanger, A., Usman, M., Murshed, M., Mahmood, H., Balsalobre-Lorente, D., 2022. The linkages between natural resources, human capital, globalization, economic growth, financial development, and ecological footprint: The moderating role of technological innovations. Resour. Policy 76, 102569. https://doi.org/10.1016/j.resourpol.2022.102569.

Juodis, A., Karavias, Y., Sarafidis, V., 2021. A homogeneous approach to testing for Granger non-causality in heterogeneous panels. Empir. Econ. 60 (1), 93–112.

Karaduman, C., 2022. The effects of economic globalization and productivity on environmental quality: Evidence from newly industrialized countries (2022). Environ. Sci. Pollut. Res. 29, 639–652. https://doi.org/10.1007/s11356-021-15717-1.

Karavias, Y., Tzavalis, E., 2016. Local power of fixed-T panel unit root tests with serially correlated errors and incidental trends. J. Time Ser. Anal. 37 (2), 222–239.

Karim, S., Naz, F., Naeem, M.A., Vigne, S.A., 2022. Is FinTech providing effective solutions to Small and Medium Enterprises (SMEs) in ASEAN countries? Econ. Anal. Policy 75, 335–344. https://doi.org/10.1016/j.eap.2022.05.019.

Khan, I., Hou, F., Le, H.P., 2021. The impact of natural resources, energy consumption, and population growth on environmental quality: Fresh evidence from the United States of America. Sci. Total Environ. 754, 142222 https://doi.org/10.1016/j.scitotenv.2020.142222.

Khraief, N., Shahbaz, M., Mallick, H., Loganathan, N., 2018. Estimation of electricity demand function for Algeria: Revisit of time series analysis. Renew. Sustain. Energy Rev. 82, 4221–4234. https://doi.org/10.1016/j.rser.2016.11.106.

Kong, X., Xu, T., 2023. How FinTech affects total factor energy efficiency? Evidence from Chinese cities. Front. Energy Res. 11, 1–13. https://doi.org/10.3389/fenrg.2023.1296820.

Kongbuamai, N., Bui, Q., Yousaf, H.M.A.U., Yousaf, H.M.A., Liu, Y., 2020. The impact of tourism and natural resources on the ecological footprint: A case study of ASEAN countries. Environ. Sci. Pollut. Res. 27, 19251–19264. https://doi.org/10.1007/s11356-020-08582-x.

Kumar, P., Gupta, S., Dagar, V., 2024. Sustainable energy development through non-residential rooftop solar photovoltaic adoption: Empirical evidence from India. Sustain. Dev. 32 (1), 795–814. https://doi.org/10.1002/sd.2644.

Le, H.P., Ozturk, I., 2020. The impacts of globalization, financial development, government expenditures, and institutional quality on CO2 emissions in the presence of environmental Kuznets curve. Environ. Sci. Pollut. Res. 27, 22680–22697. https://doi.org/10.1007/s11356-020-08812-2.

Li, X., Zhu, S., Li, Y., Chang, R., 2022. What is the asymmetric influence of natural resource rent and green innovation on the ecological sustainability of the ARCTIC region. Resour. Policy 79, 103051. https://doi.org/10.1016/j.resourpol.2022.103051.

Li, Y., Liu, C.Y.N., Lao, U., Dang, J., 2023. Navigating the path to environmental sustainability: Exploring the role of fintech, natural resources and green energy in Belt and Road countries. Resour. Policy 88, 104485. https://doi.org/10.1016/j.resourpol.2023.104485.

Lin, B., Ullah, S., 2024. Evaluating forest depletion and structural change effects on environmental sustainability in Pakistan: Through the lens of the load capacity factor. J. Environ. Manag. 353, 120174 https://doi.org/10.1016/j.jenvman.2024.120174.

Lisha, L., Mousa, S., Arnone, G., Muda, I., Huerta-Soto, R., Shiming, Z., 2022. Natural resources, green innovation, fintech, and sustainability: A fresh insight from BRICS. Resour. Policy 80, 103119. https://doi.org/10.1016/j.resourpol.2022.103119.

Liu, K., Mahmoud, H.A., Liu, L., Halteh, K., Arnone, G., Shukurullaevich, N.K., Alzoubi, H.M., 2024. Exploring the Nexus between Fintech, natural resources, urbanization, and environment sustainability in China: A QARDL study. Resour. Policy 89, 104557. https://doi.org/10.1016/j.resourpol.2023.104557.

Luo, S., Mabrouk, F., 2022. Nexus between natural resources, globalization and ecological sustainability in resource-rich countries: Dynamic role of green technology and environmental regulation. Resour. Policy 79, 103027. https://doi.org/10.1016/j.resourpol.2022.103027.

Machado, J.A., Silva, J.S., 2019. Quantiles via moments. J. Econ. 213 (1), 145–173.

Majeed, A., Wang, L., Zhang, X., Kirikkaleli, D., 2021. Modeling the dynamic links among natural resources, economic globalization, disaggregated energy consumption, and environmental quality: Fresh evidence from GCC economies. Resour. Policy 73, 102204. https://doi.org/10.1016/j.resourpol.2021.102204.

Miao, Y., Razzaq, A., Adebayo, T.S., Awosusi, A.A., 2022. Do renewable energy consumption and financial globalisation contribute to ecological sustainability in newly industrialized countries. Renew. Energy 187, 688–697. https://doi.org/10.1016/j.renene.2022.01.073.

Muganyi, T., Yan, L., Sun, H., 2021. Green finance, fintech and environmental protection: Evidence from China. Environ. Sci. Ecotechnology 7, 100107. https://doi.org/10.1016/j.ese.2021.100107.

Murshed, M., Rashid, S., Ulucak, R., Dagar, V., Rehman, A., Alvarado, R., Nathaniel, S.P., 2022. Mitigating energy production-based carbon dioxide emissions in Argentina: the roles of renewable energy and economic globalization. Environ. Sci. Pollut. Res. 29, 16939–16958. https://doi.org/10.1007/s11356-021-16867-y.

Musah, M., Owusu-Akomeah, M., Boateng, F., Iddris, F., Mensah, I.A., Antwi, S.K., Agyemang, J.K., 2022. Long-run equilibrium relationship between energy consumption and CO2 emissions: A dynamic heterogeneous analysis on North Africa. Environ. Sci. Pollut. Res. 29, 10416–10433. https://doi.org/10.1007/s11356-021-16360-6.

Nenavath, S., 2022. Impact of fintech and green finance on environmental quality protection in India: By applying the semi-parametric difference-in-differences (SDID). Renew. Energy 193, 913–919. https://doi.org/10.1016/j.renene.2022.05.020.

Okere, K.I., Dimnwobi, S.K., Ekesiobi, C., Onuoha, F.C., 2023a. Pollution, governance, and women's work: Examining African female labour force participation in the face of environmental pollution and governance quality puzzles. Women'S. Stud. Int. Forum. https://doi.org/10.1016/j.wsif.2023.102851.

Okere, K.I., Dimnwobi, S.K., Ekesiobi, C., Onuoha, F.C., 2023b. Turning the tide on energy poverty in sub-Saharan Africa: Does public debt matter. Energy. https://doi.org/10.1016/j.energy.2023.128365.

Omoju, O.E., Beyene, L.M., Ikhide, E.E., Dimnnwobi, S.K., Ehimare, O.A., 2024. Being green and prudent: Economy-wide and environmental impacts of renewable energy production subsidy in Nigeria. J. Dev. Areas 58 (3), 47–66.

Onifade, S.T., Gyamfi, B.A., Haouas, I., Bekun, F.V., 2021. Re-examining the roles of economic globalization and natural resources consequences on environmental degradation in E7 economies: Are human capital and urbanization essential components? Resour. Policy 74, 102435. https://doi.org/10.1016/j.resourpol.2021.102435.

Onuoha, F.C., Dimnwobi, S.K., Okere, K.I., Ekesiobi, C., 2023a. Funding the green transition: Governance quality, public debt, and renewable energy consumption in Sub-Saharan Africa. Uti. Policy. https://doi.org/10.1016/j.jup.2023.101574.

Onuoha, F.C., Dimnwobi, S.K., Okere, K.I., Ekesiobi, C., 2023b. Sustainability burden or boost? examining the effect of public debt on renewable energy consumption in Sub-Saharan Africa. Energy Sources, Part B: Econ., Plan., Policy 18 (1), 1–15. https://doi.org/10.1080/15567249.2023.2214917.

Opoku-Mensah, E., Chun, W., Tuffour, P., Chen, W., Agyapong, R.A., 2023. Leveraging on structural change and ISO 14001 certification to mitigate ecological footprint in Shanghai cooperation organization nations. J. Clean. Prod. 414, 137542 https://doi.org/10.1016/j.jclepro.2023.137542.

Ozturk, S., Cetin, M., Demir, H., 2022. Income inequality and CO2 emissions: nonlinear evidence from Turkey. Environ., Dev. Sustain. 24, 11911–11928. https://doi.org/10.1007/s10668-021-01922-y.

Pata, U.K., Kartal, M.T., 2023. Impact of nuclear and renewable energy sources on environment quality: Testing the EKC and LCC hypotheses for South Korea. Nucl. Eng. Technol. 55 (2), 587–594. https://doi.org/10.1016/j.net.2022.10.027.

Pesaran, M.H. (2004). General diagnostic tests for cross section dependence in panels. Cambridge Working Papers in Economics 0435, Faculty of Economics, University of Cambridge.

Pesaran, M.H., 2007. A pair-wise approach to testing for output and growth convergence. J. Econ. 138 (1), 312–355.

Pesaran, M.H., Yamagata, T., 2008. Testing slope homogeneity in large panels. J. Econ. 142 (1), 50–93.

Raghavendra, C., Mahesh, R., Khan, M.K., Dagar, V., Singh, S., Alvarado, R., 2024. Impact of carbon emissions, renewable and non-renewable energy consumption on inbound cross-border mergers and acquisition's investment inflow. E*nvironment, Dev. Sustain.* https://doi.org/10.1007/s10668-024-04511-x.

Rao, A., Dagar, V., Sohag, K., Dagher, L., Tanin, T.I., 2023. Good for the planet, good for the wallet: The ESG impact on financial performance in India. Financ. Res. Lett. 56, 104093 https://doi.org/10.1016/j.frl.2023.104093.

Rasool, Y., Jianguo, D., Ali, K., 2023. Exploring the linkage between globalization and environmental degradation: a disaggregate analysis of Indonesia. Environ., Dev. Sustain. https://doi.org/10.1007/s10668-023-03315-9.

Sabir, S., Gorus, M.S., 2019. The impact of globalization on ecological footprint: empirical evidence from the South Asian countries. Environ. Sci. Pollut. Res. 26, 33387–33398. https://doi.org/10.1007/s11356-019-06458-3.

Sadiq, M., Paramaiah, C., Joseph, R., Dong, Z., Nawaz, M.A., Shukurullaevich, N.K., 2023. Role of fintech, green finance, and natural resource rents in sustainable climate change in China. Mediating role of environmental regulations and government interventions in the pre-post COVID eras. Resour. Policy 88, 104494. https://doi.org/10.1016/j.resourpol.2023.104494.

Sakariyahu, R., Lawal, R., Etudaiye-Muhtar, O.F., Ajide, F.M., 2023. Reflections on COP27: How do technological innovations and economic freedom affect environmental quality in Africa? Technol. Forecast. Soc. Change 195, 122782. https://doi.org/10.1016/j.techfore.2023.122782.

Sherbinin, A.D., Carr, D., Cassels, S., Jiang, L., 2007. Population and environment. Annu. Rev. Environ. Resour. 32, 345–373.

Siche, R., Pereira, L., Agostinho, F., Ortega, E., 2010. Convergence of ecological footprint and emergy analysis as a sustainability indicator of countries: Peru as case study. Commun. Nonlinear Sci. Numer. Simul. 15 (10), 3182–3192. https://doi.org/10.1016/j.cnsns.2009.10.027.

Statista (2023). Share of fintech companies in North Africa 2020, by select countries. ⟨https://www.statista.com/statistics/1256108/share-fintech-firms-in-north-africa-by-select-country/⟩.

Shouwu, J., Xu, T., Shehzad, K., Zaman, B.U., Wuyue, L., 2024. The role of environmental technologies and clean energy transition in shaping the N-shaped environmental Kuznets curve: a North African perspective. Environ. Technol. Innov. 33, 103463 https://doi.org/10.1016/j.eti.2023.103463.

Tao, R., Su, C., Naqvi, B., Rizvi, S.K.A., 2021. Can Fintech development pave the way for a transition towards low-carbon economy: a global perspective. Technol. Forecast. Soc. 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 Dev. Sustain. 3, 100096 https://doi.org/10.1016/j.wds.2023.100096.

Udeagha, M.C., Muchapondwa, E., 2023a. Striving for the United Nations (UN) sustainable development goals (SDGs) in BRICS economies: the role of green finance, fintech, and natural resource rent. Sustain. Dev. 31 (5), 3657–3672. https://doi.org/10.1002/sd.2618.

Udeagha, M.C., Muchapondwa, E., 2023b. Green finance, fintech, and environmental sustainability: fresh policy insights from the BRICS nations. Int. J. Sustain. Dev. World Ecol. 30 (6), 633–649. https://doi.org/10.1080/13504509.2023.2183526.

Udemba, E.N., Dagar, V., Peng, X., Dagher, L., 2024. Attaining environmental sustainability amidst the interacting forces of natural resource rent and foreign direct investment: is Norway any different? OPEC Energy Rev. 48 (1), 19–35. https://doi.org/10.1111/opec.12292.

Ugwu, J.N., Nwani, C., Okere, K.I., Agbanike, T.F., 2022. Regulatory impediments to carbon emission mitigation in Sub-Saharan Africa: the impact of a hostile business environment and high tax burden. Environ. Sci. Pollut. Res. 29 (29), 43845–43857.

Usman, M., Balsalobre-Lorente, D., Jahanger, A., Ahmad, P., 2021. Pollution concern during globalization mode in financially resource-rich countries: do financial development, natural resources, and renewable energy consumption matter. Renew. Energy 183, 90–102. https://doi.org/10.1016/j.renene.2021.10.067.

Usman, M., Balsalobre-Lorente, D., 2022. Environmental concern in the era of industrialization: can financial development, renewable energy and natural resources alleviate some load? Energy Policy 162, 112780. https://doi.org/10.1016/j.enpol.2022.112780.

Usman, M., Jahanger, A., Makhdum, M.S.A., Balsalobre-Lorente, D., Bashir, A., 2022. How do financial development, energy consumption, natural resources, and globalization affect Arctic countries' economic growth and environmental quality?

An advanced panel data simulation. Energy 241, 122515. https://doi.org/10.1016/j.energy.2021.122515.
Villanthenkodath, M.A., Pal, S., 2024. Environmental degradation in geopolitical risk and uncertainty contexts for India: a comparison of ecological footprint, CO2 emissions, and load capacity factor. Energy Clim. Change 5, 100122. https://doi.org/10.1016/j.egycc.2023.100122.
Wang, L., Vo, X.V., Shahbaz, M., Ak, A., 2020. Globalization and carbon emissions: Is there any role of agriculture value-added, financial development, and natural resource rent in the aftermath of COP21? J. Environ. Manag. 268, 110712 https://doi.org/10.1016/j.jenvman.2020.110712.
Wen, J., Mughal, N., Zhao, J., Shabbir, M.S., Niedbała, G., Jain, V., Anwar, A., 2021. Does globalization matter for environmental degradation? Nexus among energy consumption, economic growth, and carbon dioxide emission. Energy Policy 153, 112230. https://doi.org/10.1016/j.enpol.2021.112230.
Westerlund, J., 2007. Testing for error correction in panel data. Oxf. Bull. Econ. Stat. 69 (6), 709–748.
Xia, A., Liu, Q., 2024. Modelling the asymmetric impact of fintech, natural resources, and environmental regulations on ecological footprint in G7 countries. Resour. Policy 89, 104552. https://doi.org/10.1016/j.resourpol.2023.104552.
Xiaoman, W., Majeed, A., Vasbieva, D.G., Wati Yameogo, C.E., Hussain, N., 2021. Natural resources abundance, economic globalization, and carbon emissions: advancing sustainable development agenda. Sustain. Dev. 29 (5), 1037–1048. https://doi.org/10.1002/sd.2192.
Xu, L., Wang, X., Guo, W., 2022. Does renewable energy adaptation, globalization, and financial development matter for environmental quality and economic progress? Evidence from panel of big five (B5) economies. Renew. Energy 192, 631–640. https://doi.org/10.1016/j.renene.2022.05.004.
Zeraibi, A., Radulescu, M., Shehzad, K., Khan, M.K., Usman, M., 2023. Exploring the impact of public funds and eco-friendly innovations on reducing carbon pollution in North Africa. Environ. Sci. Pollut. Res. 30, 122906–122920. https://doi.org/10.1007/s11356-023-30985-9.
Zhang, L., Godil, D.I., Bibi, M., Khan, M.K., Sarwat, S., Anser, M.K., 2021. Caring for the environment: How human capital, natural resources, and economic growth interact with environmental degradation in Pakistan? A dynamic ARDL approach. Sci. Total Environ. 774, 145553 https://doi.org/10.1016/j.scitotenv.2021.145553.
Zhang, Y., Zheng, K., Xia, F., Cheng, Z., 2024. Fintech, natural resource rents, renewable energy consumption and environmental quality: a perspective of green economic recovery from BRICS economies. Resour. Policy 89, 104604. https://doi.org/10.1016/j.resourpol.2023.104604.
Zhao, X., Adebayo, T.S., Kong, X., Al-Faryan, M.A.S., 2022. Relating energy innovations and natural resources as determinants of environmental sustainability: the role of globalization in G7 countries. Resour. Policy 79, 103073. https://doi.org/10.1016/j.resourpol.2022.103073.