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Revisiting the Environmental Kuznets Curve: A Panel-Econometric Exploration of Green Innovation's Mediating Role in the Nexus of Fintech, Green Finance, and Energy Transition (2000–2022)

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This study conducts an in-depth investigation into the environmental factors driving degradation and the role of innovations in fostering sustainable development, employing the Environmental Kuznets Curve (EKC) hypothesis. Using panel data from 60 countries over 22 years (2000–2022), the research applies advanced econometric techniques, including Generalized Method of Moments (GMM) and Granger causality tests, to address endogeneity, heteroscedasticity, and serial correlation. The findings reveal that green finance, energy transition, and financial technology (fintech) significantly reduce environmental degradation, whereas inadequate waste management exacerbates it. Additionally, green innovation emerges as a critical mediator, enhancing the effectiveness of these factors in mitigating environmental harm. The study bridges key knowledge gaps, offering policymakers actionable insights into leveraging green finance, renewable energy, and fintech for sustainable development while underscoring the need for improved waste management strategies.

1. Introduction

Climate change is a major challenge for human survival and development. The existing global consumption patterns driven by energy-intensive economic growth and the over-exploitation of natural resources are a serious threat to inter-generational equity. Over the last half-century, the ecological footprint (EF) has increased by about 190%, suggesting an increasing imbalance in humans' relationship with nature. Nowadays, most countries have a legal obligation to apply measures aimed at reducing greenhouse gas emissions as part of their strategies to keep global warming below 2°C and preferably below 1.5°C compared to pre-industrial levels (Udeagha & Ngepah, 2023). Fossil fuel dependent economies that have historically prioritized GDP growth over environmental sustainability are now worried by the continued rise in global carbon dioxide (CO2) emissions out of these nations (Hao & Chen, 2024; Udeagha & Breitenbach, 2023). They tend to be called developing countries where little technological progress has been made, relying heavily on domestic as well as imported fossil fuels for energy generation, thus earning significant economic gains at the expense of environmental integrity within their energy industries. Nevertheless, today's economy does not make it possible for us to continue pursuing economic development without ensuring ecological balance particularly through managing CO2 emissions. Therefore, researchers today focus on decreasing CO2 emissions contributing towards sustaining our world and making it ecologically friendly especially such factors as green finance (GFN), Financial Technologies (fintech's) among others (Udeagha & Ngepah, 2023). Natural resources are crucial to economic growth and development across the globe.

Similarly, further exploration and consumption of fossil fuels pose difficulties for environmental sustainability just as ownership of land-based natural deposits including coal mines becomes a hurdle on the path towards transition to renewable energies (Ahmadov et al., 2019). Thus, burning oil, gas or coal releases harmful pollutants into the atmosphere contributing to climate change through the greenhouse effect. Again, too much dependence on resource rentals can hamper diversification into other sectors like renewable energy (Huang, 2022). Therefore, examining how moving to renewables impacts our planet is important in developing strategies that will effectively address climate change. The Paris Agreement on Climate Change, established in 2015, seeks to deal with climate change's environmental and social risks. Worldwide countries are now required by law to have action plans aimed at reducing greenhouse gas emissions, leading to the target of keeping global warming below 2 degrees C above pre-industrial levels or even better not exceeding 1.5 degrees C. Nevertheless, the increasing levels of carbon dioxide (CO2) emissions remain a serious worry particularly for economies that largely rely on fossil fuels for economic advancement. These economies which are often referred to as emerging economies and have limited technological advancement have historically placed higher priority on economic gains as compared to environmental protection.

A critical global challenge, environmental degradation is caused by the unsustainable use of natural resources, rapid industrialization and urbanization. They aim to deal with these issues. This study investigates various dimensions of human activities towards environmental health deterioration like air, water and soil pollution. The research therefore seeks to recognize possible corrective measures in mitigating or lessening the effect of contributing factors through analyzing their relationships between each other. As a result, it will help shape policies and create awareness among citizens for the sake of our planet's survival for many years to come. The significance of this study elaborates connections between green finance, waste management, energy transition, fintech, and green innovation to address environmental concerns. It aims to provide insights for policymakers, financial institutions, enterprises, and environmental organizations to mitigate environmental degradation by promoting sustainable practices, investments, and innovative technologies, ultimately fostering a culture of sustainability and environmental responsibility. The following research paper is structured as the 2nd section includes the relevant literature to identify the potential gap. 3rd section is methodology which contains the details of variables, data, data collection techniques, research onion, and the theoretical support with hypothesis development. 4th Section is the basic data analysis and diagnostics of the panel data issues with relevant methods. However, the 5th section is about conclusion and recommendation which will conclude the study.

2. Literature Review

2.1 Environmental Degradation

The importance of technology and science in fostering the integration of ecological and economy has been emphasized. Sustainable development became fashionable during this process (Ma et al., 2022). We believe it is crucial to watch how two sets of rising economies from two regions experience different social and economic variables affecting the development of environmental degradation. The foundation for pollutant relocation in developing nations may be the establishment of more stringent regulations pertaining to environmental protection in wealthy nations. The requirement for rising economies to close the gap between growth and standard for living also plays a part in this. Sustained economic growth, guaranteeing the means to attain welfare and a high quality of living through investments in public services (education, good health, facilities or culture), and individual consumption are the key components of an advanced economy (and society) (Hunjra et al., 2023). Urbanization, which provides resources unavailable to rural civilization, is another crucial aspect of modern society (Dilanchiev et al., 2023).

2.2 Green Finance & Environmental Degradation

It is often known that green finance plays a crucial role in advancing environmentally friendly growth and environmental protection. In the past, attempts to reduce carbon emissions through traditional methods like carbon taxes and emissions laws have not always been successful. Investing in green projects bears a considerable lot of risk because carbon dioxide emission trading systems, and specifically papers purchased on financial markets, are far more unpredictable than the stock market (Chin et al., 2024a). Conversely, carbon taxes move slowly, which makes it challenging to initiate substitution processes, even though they are stable and simple to enact. Moreover, they might be passed on to customers, which would decrease the incentive for businesses to convert to ecologically friendly machinery (Chin et al., 2024b) who examine the global landscape, the Belt and Road economies' environmental loads have shifted because of advantageous trade agreements and foreign direct investment. It's interesting to note that ecological requirements in trade agreements are shown to have no real bearing on the problem of transferring the pollution load. Research indicates that the shifting of the pollution load due to technological advancements disproportionately affects middle-income countries (D. Zhang et al., 2021a). Therefore, one alternate strategy for preserving the environment is to explicitly encourage investments in green technologies. One method to do this is by involvement of government (Xu et al., 2023).

2.3 Energy Transition & Environmental Degradation

The progressive energy shift away from fossil fuel supply has drawn a lot of attention, not least because of its potential to reduce environmental harm. In their 2020 study, (Gencer et al., 2021). found that energy transition can help combat pollution and emphasized the need to reduce emissions in industrial and transport sectors. They pointed out that achieving sustainable development goals or SDGs will require more than switching to greener sources of energy. Research by (Cardoso & González, 2019) showed how incorporation of energy transitions early enough can save on the costs of obsolete equipment and address environmental problems related to changes in the amount of consumed domestic and thermal energy. According to (Kokkinos et al., 2020), managing urban energy demands is critical especially in emerging nations, as they discussed renewable energy transition implications on environmental sustainability. An earlier analysis on the association among economic expansion and the energy transition by (Kander & Stern, 2014) found that transitioning away from conventional to alternative sources of energy offers better chances for steady long-term economic growth.

2.4 Waste Management & Environmental Degradation

They include metropolitan solid waste (MSW) which is a major part of the total generation global solid waste together with construction and demolition waste (CDW) which also contributes to over 70 per cent of the total solid waste (Modak et al., 2018). The effective management regarding such waste types eradicates over half of the issue of waste disposal in the world besides helping in achieving transition towards a sustainable future that shall be the norm in the future (Grosso & Falasconi, 2018). Nevertheless, MSW and particularly CDW have been disposed of in the open spaces of developing countries even though there is a chance to recycle it (Ferronato & Torretta, 2019; Mama et al., 2021). There is therefore the need to enact policies that can be useful in working towards the achievement of this; shift towards sustainability (Brunner & Fellner, 2007). In China and India only 5% % CDW is recycled while the rest which is approximately 95% is disposed in landfill (Duan et al., 2019). Utilizing CE concepts such as designing circular economy, recycling economic resources to save cost, and prevent environmental pollution, due to the problem of global illicit administration of CDW and open dumping (Fahim et al., 2018). Generally, when waste is dumped into a landfill, there is always a creation of leachate.

2.5 Fintech & Environmental Degradation

Financial technologies, or FinTech, encompass the integration and advancement of technology and finance, resulting in both disruptive and incremental innovations such as mobile payments, internet banking, peer-to-peer lending, crowdfunding, online identification, and robo-advisory services. FinTech startups play a significant role in this evolving landscape (S. Li et al., 2024). The literature has rarely examined potential factors influencing environmental quality, especially the ecological footprint, including the effects of environmental-related technology, financial innovation, and globalization. According to Hussain & Dogan, (2021) both long-term and short-term impacts of environmental technologies and institutional quality on the ecological footprint are analyzed (Huo et al., 2023). (Ahmad et al., 2020) and (Hussain & Dogan, 2021) explore the dynamic relationships between the ecological footprint, natural resource rents, technological innovation, and economic activity. Technological advancements are seen as an effective strategy to mitigate environmental damage. Another intriguing study by (Destek & Manga, 2021a). The study of Khan, S., Bangash, R., & Ullah, U. (2023) evaluates various models using the business risk metric Value at Risk (VaR) to identify the most suitable framework for the KMI-30 stock market. The results indicate that although past banking experiences may not directly influence customers, several mediating factors play a significant role in shaping their willingness to adopt RAAST (Ullah, U., Khan, J., Shah, J. A., & Baloch, R. 2023). Fintech applications can provide special effusion for righting the ecosystem, improving the samples of ecological stability

(Su et al., 2022). To this end, the purpose of this study was to establish the extent to which environmental conditions around the country had improved due to the expansion of the fintech industry.

2.6 Green innovation & Environmental Degradation

Technological innovation's rapid progress has had a significant impact on the outcomes of environmental policy. After carrying out an extensive investigation to investigate the impact of green innovation on the ecological footprint in BEM economies, Destek & Manga (2021b) concluded that technological innovation currently has a minor impact on environmental sustainability. Lei et al. (2022) study on the environmental performance of businesses indicates that reliance on outdated technologies has a negative effect on environmental quality in developing economies. Bashir et al. (2023) investigated how technical advancements affected the Environmental Footprint (EFP) in industrial economies and discovered that advanced technology advancements contributed to environmental sustainability and had a positive impact on EFP. Rout et al. (2022) used sophisticated econometric techniques to study the causal relationship between green technology and EFP from 1985 to 2016. Lately, green innovation has won much attention due to its ability to effectively tackle environmental problems. This includes the creation of new instruments, products and systems that minimize environmental impacts, save resources and promote sustainability. For example, this notion entails the development of innovative green technologies, ecological research and development, as well as greener industrial processes (Sadiq et al., 2022).

2.7 Natural Resources Rent & Environmental Degradation

The availability of natural resources, combined with technological advancements and cleaner energy sources, may reduce our dependence on fossil fuels. Human activities such as deforestation, chainsaw operations, and mining contribute significantly to the degradation of natural ecosystems and pollution (Y. Zhang & Dilanchiev, 2022). Research on the role of natural resources in environmental conservation is still inconclusive. While Taghizadeh-Hesary et al. (2023a) suggest that natural resources contribute to ecological contamination, other studies, such as Albats et al. (2020) presented a different perspective. Tourism, one of the fastest-growing industries globally, exemplifies this debate. Although tourism and natural resource industries contribute to financial development through high energy usage, the resulting waste negatively impacts environmental quality. The development of tourism is influenced by natural resources, financial growth, energy consumption patterns, and ecological deterioration. Increased fossil fuel use for transportation and lodging in tourism has heightened air pollution and atmospheric CO_2 levels, accelerating the depletion of natural resources. Due to its rapid growth, tourism is recognized as one of the most energy-intensive industries, with certain travel and lodging activities consuming substantial energy and exacerbating CO_2 emissions. Current research often overlooks how tourism growth influences and predicts energy consumption patterns (Taghizadeh-Hesary et al., 2023b).

Natural resources are widely acknowledged as essential for the economic and cultural development of any society (Hu et al., 2022). While natural resources play a vital role in financial growth, the demand for clean air increases as economies progress, leading to enhancements in environmental quality. Therefore, balancing economic development with natural resource conservation is critical for maintaining the planet's ecological balance. Natural resources meet various human, and tourist needs, such as purifying air, providing food and shelter, and serving as materials for attractions. However, rapid exploitation or improper extraction of natural resources can result in environmental degradation. Additionally, the "natural resource curse" is a reality that China's green development transition has faced to some extent, as resource-rich areas tend to experience more severe resource and ecological difficulties (Liu et al., 2022). This curse hampers green development transitions for several reasons. This study can provide valuable insights into natural resources, green economic growth, and balanced regional economic growth in developing economies (Yu, 2023).

2.8 Trade Openness & Environmental Degradation

The association of trade openness and carbon emission has been debated for a long time and it is an important issue in trade policies. Several researchers have studied the impact of trade openness and its impact on environmental quality, but they have found mixed results. Some researchers in the proceeding literature argue that trade openness is harmful for environmental quality where some have stated that trade openness is good for the quality of environment and some others have found even no association between the two (H. Khan et al., 2021). Moreover, Ertugrul et al. (2016) argue that their study variables were cointegrated for some countries and trade openness, energy consumption, and real income are the main drivers of carbon emission in their sample countries in the long run Ho & Iyke (2019) have found that high level of trade openness is related to low emission in the long run while high openness is associated with high carbon emission in short run. Although green innovation has been widely recognized as a transformative power, it is always necessary to have more empirical studies to establish its mediating effect on environmental degradation and independent variables involved. It is important therefore that these gaps are addressed so as to develop comprehensive plans that maximize fintech, waste management, energy transition and green financing while jointly addressing environmental detriment.

3. Methodology

3.1 Variables Description

Researchers used to measure environmental degradation with carbon dioxide emissions (kt) (Opoku et al., 2022). while some authors use total greenhouse gas emissions (kt of CO2 equivalent) (Acheampong & Opoku, 2023). This study used proxies by CO2 emissions according to Nuţă et al., (2024). This study assessed the fintech index using two indicators national internet usage and mobile subscription usage using data from the WDI. The impact of independent factors such waste management, energy transition, green finance, and financial technology on environmental deterioration is investigated in this study. The relationship between environmental deterioration and green innovation is moderated by natural resource rent, whereas green innovation serves as a mediator. The green finance index (GFI) is used to measure green finance; a proportion of total electricity output is used to measure energy transition (Sadiq et al., 2024); the percentages of total energy from waste and combustible renewables is used to measure waste management (Chien et al., 2023); and mobile subscriptions and browsing habits are used to measure by the given references of different authors they used proxies to measure the variables. This research examines the relation and role of mediating variable green innovation between independent variables, green finance, energy transition, waste management, Fintech, and dependent variable environmental degradation. Many researchers used to measure green innovation by environmental technologies (Sun & Razzaq, 2022). The research examines the role and checks relation of moderator variable natural resource rent in between green innovation and environmental degradation. Some researchers used % GDP to measure natural resource rent including X. Li et al.

(2022). This study used proxy Total natural resources rent (% of GDP) for the moderator variable which is used previously by Khan et al. (2023).

Table No 1: Description of Variables

Variable	Description	Symbol	Database
Environmental Degradation	Per capita carbon dioxide (CO_2) emissions metric tons	ED	WDI
Green Finance	measure green finance (refers to green finance index (GFI))	GF	OECD
Energy Transition	Renewable electricity output (REO) (% of total electricity output	ET	WDI
Waste Management	Combustible renewables and waste (% of total energy)	WM	WDI
Fintech	Mobile subscription & Internet Usage		
Green Innovation	Environment technologies	GI	OECD
Natural Resource Rent	(% of GDP)	NRR	WDI

3.2 Control Variables

The control variables of the study are trade openness, urbanization, and industrialization. There are various indicators of trade openness in literature. some researcher measured the trade openness by sum of import and export (% of GDP) (Fang et al., 2020). There are different indicators for these variables in the literature. Some studies measure industrialization by the industry share as a percentage of GDP (Majeed & Tauqir, 2020). Some studies measure industrialization by ratio of industrial value added to the GDP (Shao et al., 2023). This Study measure industrialization by the ratio of industrial value added to GDP as This indicator is rarely used in the nexus between the green finance and sustainable development. There are different indicators of trade openness in the literature. Some studies measure trade openness by sum of import and export percentage of GDP (Fang et al., 2020).

3.4 Econometric Techniques

This article explores how green financial indicators, like climate financing, digital financial inclusion, industrialization, financial development, financial globalization, soft infrastructure, energy transition, and eco-innovation, are connected to sustainable development. The research involves several steps in analyzing panel data. It starts with basic statistics and a test to see if the data is stable. The study takes use of co-integration testing, cross-sectional dependency, descriptive analysis, second unit root test, and several diagnostic tests. Lastly, the moderating effect of Energy Efficiency (EFF) is taken into consideration as the study used GMM to explain the link between the variables. Following a similar approach as a previous study by (Zhu et al., 2023). This article transforms data using the natural logarithm for certain variables and employs techniques to standardize and address any outliers or skewness in the dataset.

3.5 VIF (Variance Inflation Factor)

Belsley (1984) introduced the Variance Inflation Factor (VIF), The VIF is a widely used statistical measure used to evaluate the degree of multicollinearity among predictor variables in regression analysis.

$$VIFi = 1/(1 - R^2 i) \quad \ldots \text{Eq (1)}$$

The Variance Inflation Factor (VIFi) is used to represent the i-th predictor, while the R2 value is determined by regressing it against all other predictors.

3.6 Cross sectional Dependency Test Equation

To determine whether cross-sectional dependence exists in the residuals of an estimable model, employ cross-sectional dependency tests (Chudik & Pesaran, 2015).

$$y_i = p \sum_{j=1}^{N} \omega_{ij} y_j + \beta X_j + \in_i \quad \text{Eq… (2)}$$

yi is dependent variable, p is spatial autoregressive parameter wij shows the spatial weight while beta is coefficient vector.

3.7 Co-Integration Test

Westerlund (2005) formation of cointegration test for examine the long-term relationship among variables in a dataset, typically involving panel data.

$$\Delta Yit = \beta 0 + \beta 1t + \beta_2 y_{i,t} + \sum_{j=1}^{p} \alpha_j \Delta x_{ij,t} + \sum_{j=1}^{p} \gamma_i x_{ij,t-1} + \varepsilon_{it} \quad \text{Eq… (3)}$$

$$\Delta y_{it} = \beta 0 + \beta_1 t + \sum_{j=1}^{p} \alpha_j \Delta x_{ij,t} + \boldsymbol{\lambda_i} + \pi_t + \boldsymbol{\varepsilon_{it}} \quad \text{Eq… (4)}$$

Pedroni (1999) developed the pedroni test for the testing of co-integration. Δyit and Δxij,t are first difference as λi and πt are individual and t is time effects while εit is the error term.

3.8 Second Generation unit root test

Pesaran (2007) utilizes cross-sectional ADF statistics to add lagged levels and first differences to Augmented Dickey-Fuller regressions, proxying common factors using Yi,t and lagged values.

$$\Delta y_{i,t} = \alpha i + \beta i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \delta_i \Delta \bar{y}_i + \epsilon_{i,t} \quad \text{Eq… (5)}$$

where the mean of lagged levels is y^{t−1, the mean of first-differences is y^i, the error terms are εi,t, and the slope coefficients αi, βi, γi, and δi are derived from the ADF test for the country.

The study introduces modified IPS statistics based on the average of individual CADF, known as Pesaran's CIPS test, to enhance the overall IPS.

$$\text{CIPS} = \frac{1}{\text{N}} \sum_{\text{t=i}}^{\text{N}} \text{ti}(\text{N}, \text{T}), \quad \text{Eq… (6)}$$

3.9 Slope of Homogeneity

Swamy (1970) developed the framework in which slope coefficient of cointegration in found homogeneous. Pesaran & Yamagata (2008) improved the Swamy homogeneity slope test and develop two more delta tests statistics like delta bar and delta bar adj.

$$\tilde{\Delta}= \sqrt{N}\left(\frac{N^{-1}\bar{S}-k}{\sqrt{2k}}\right) \sim X_k^2 \quad \text{Eq… (7)}$$

$$\tilde{\Delta}adj = \sqrt{N}\left(\frac{N^{-1}\bar{S}-k}{v(T,k)}\right) \sim N(0,1) \quad \text{Eq… (8)}$$

N represents the number of cross-section units; S stands for the statistics from the Swamy test; k stands for the independent variables; and p values indicate the significance level. Additionally, adj is a mean variance bias corrected variant of delta bar adj which functions well for both big and small samples. Pesaran & Yamagata (2008) created a reliable slope homogeneity test utilizing the Heteroscedasticity and Autocorrelation Consistent (HAC) statistical model.

$$\Delta\, HAC = \sqrt{N}\left(\frac{N^{-1}S_{HAC}-k}{\sqrt{2k}}\right) \sim X_k^2 \quad \text{Eq… (9)}$$

$$(\Delta\, HAC)adj = \sqrt{N}\left(\frac{N^{-1}S_{HAC}-k}{v(T,k)}\right) \sim N(0,1) \quad \text{Eq… (10)}$$

3.5 Empirical Model

This section provides a mathematical representation of the relationships between the independent variables (green finance, energy transition, waste management, fintech), the mediating variable (green innovation), and the dependent variables (environmental degradation). This section employs statistical methods to estimate the quantitative impact of these variables on environmental degradation. Through the formulation of an econometric equation, the study seeks to provide empirical evidence and insights into the key drivers and mechanisms that shape these relationships, thereby supporting evidence-based decision making and policy formulation in the pursuit of environmental degradation. This model shows the influence of green finance, energy transition, waste management and fintech on environmental degradation. Equation 2 & 3 are the extension of equation 1, which includes the mediation of green innovation and control variables. This model is adapted from the study (D. Zhang et al., 2021b) and expended.

ED= f (GF, ET, WM, Fintech) ……………. (11)

The above function implies that green finance, energy transition, waste management and fintech on environmental degradation.

$$ED_{it} = \beta_0 + \beta_1 GF_{it} + \beta_2 ET_{it} + \beta_3 WM_{it} + \beta_4 Fintech_{it} + \mu_i + \epsilon_{it} \ldots \quad (12)$$

$$ED_{it} = \beta_0 + \beta_1 GF_{it} + \beta_1 ET_{it} + \beta_2 WM_{it} + \beta_3 Fintech_{it} + \beta_4 MGI_{it} + \mu_{it}.MV_{it}\partial_1 NRR_{it} + \mu_{it} \quad (13)$$

This model shows the impact of green finance, energy transition, waste management, Fintech, which includes independent variables, the mediator green innovation and moderator variables is natural resource rent. What do the letters I and t mean individual nations and eras, correspondingly. The erroneous term is (μit). β is the vector for the dependent variable as ED=Environmental degradation. The erroneous term is (μit). β is a vector for the independent variables. Where M represents the mediator and moderator variables.

$$ED_{it} = \beta_0 + \beta_1 GF_{it} + \beta_1 ET_{it} + \beta_2 WM_{it} + \beta_3 Fintech_{it} + MV_{it}\partial_1 ED_{it} + \mu_{it} + C_1 TO_{it} + C_2 URB_{it} + C_3 IND_{it} + \mu_{it} \quad (14)$$

C represents the control variables as the used variables are urbanization trade openness and industrialization.

4. Analysis and Results

4.1 Descriptive Statistics

Table No 2: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ED	1140	7.234	10.416	.055	78.637
GF	1140	13.511	8.76	.789	85.71
ET	1140	22.943	24.339	0	91.31
WM	1140	14.523	20.592	0	87.721
Fintech	1140	.917	4.315	-3.639	30.232
GI	1140	5.016	2.134	-2.98	7.903
NRR	1140	7.134	12.172	0	66.06
URB	1140	29.485	20.991	2.763	90.893
IND	1140	28.836	13.816	6.638	98.88
TO	1140	71.684	35.88	.629	252.495

Table 2 reveals descriptive statistics that Environmental degradation (ED) has a mean of 7.234 (SD = 10.416) with values ranging from 0.055 to 78.637. Green finance (GF) averages 13.511 (SD = 8.76), ranging from 0.789 to 85.71. Energy transition (ET) shows a mean of 22.943 (SD = 24.339) with values from 0 to 91.31. Waste management (WM) has a Mean of 14.523 (SD = 20.592) ranging from 0 to 87.721. Fintech averages 0.917 (SD = 4.315) with a range of -3.639 to 30.232, while Green Innovation (GI) has a mean of 5.016 (SD = 2.134) with values from -2.98 to 7.903. Natural resource rent (NRR) shows a mean of 7.134 (SD = 12.172) ranging from 0 to 66.06. Urbanization (URB) averages 29.485 (SD = 20.991) with values from 2.763 to 90.893. Industrialization (IND) has a mean of 28.836 (SD = 13.816) ranging from 6.638 to 98.88, and trade openness (TO) averages 71.684 (SD = 35.88) with a range of 0.629 to 252.495.

4.2 Correlation Test

Table No 3: Correlation Results

Variables	VIF	ED	GF	ET	WM	Fintech	GI	NRR
ED		1						
GF	1.11	-0.02	1					
ET	1.68	-0.3	0.019	1				
WM	1.83	-0.02	0.027	0.565	1			
Fintech	1.06	0.017	0.143	0.009	-0.02	1		
GI	1.96	0.303	-0.15	-0.38	-0.43	0.044	1	
NRR	3.27	0.279	0.283	-0.16	-0.04	0.128	-0.37	1

The table 3 shows Variance Inflation Factor (VIF) and Pearson correlation coefficients for variables related to environmental and economic factors. All VIF values are below 10, indicating no severe multicollinearity. Environmental Degradation (ED) has a very weak negative correlation with Green Finance (GF) (-0.02) and Waste Management (WM) (-0.02), a moderate negative correlation with Energy Transition (ET) (-0.30), and moderate positive correlations with Green Innovation (GI) (0.303) and Natural Resource Rent (NRR) (0.279). GF shows weak correlations with most variables, except for a moderate positive correlation with NRR (0.283). ET has a strong positive correlation with WM (0.565) and moderate negative correlation with GI (-0.38). WM shows a moderate negative correlation with GI (-0.43). Fintech has weak correlations with other variables, while GI has a moderate negative correlation with NRR (-0.37). These correlations indicate varying degrees of linear relationships among the variables.

4.3 Cross Sectional Dependency Test

Table No 4: Cross Sectional Dependency Test

Variable	CD-test	p-value	average joint T	mean p	mean abs(p)
ED	7.28	0.00	19.00	0.04	0.60
GF	17.17	0.00	19.00	0.09	0.27
ET	9.60	0.00	19.00	0.05	0.54
WM	-1.71	0.09	19.00	-0.01	0.56
Fintech	130.80	0.00	19.00	0.71	0.81
GI	121.76	0.00	19.00	0.66	0.75
NRR	67.85	0.00	19.00	0.37	0.46

Table 4 shows cross-sectional dependency test results reveal significant relationships between most variables across observations. Environmental degradation (ED) has a CD-test statistic of 7.28 and a p-value of 0.00, indicating strong cross-sectional dependency. Similarly, green finance (GF) shows significant dependency with a CD-test statistic of 17.17 and a p-value of 0.00. Energy transition (ET) also demonstrates significant cross-sectional dependency (CD-test statistic of 9.60, p-value of 0.00). Financial technology (Fintech) exhibits very strong dependency (CD-test statistic of 130.80, p-value of 0.00), as does green innovation (GI) (CD-test statistic of 121.76, p-value of 0.00). Natural resource rent (NRR) shows significant cross-sectional dependency as well (CD-test statistic of 67.85, p-value of 0.00). In contrast, waste management (WM) does not show significant cross-sectional dependency, with a CD-test statistic of -1.71 and a p-value of 0.09. Overall, the results indicate that most variables (ED, GF, ET, Fintech, GI, and NRR) are correlated across different observations, while WM shows minimal correlation.

4.4 Second Generation Unit Root Test

Table No 5: Second Generation Unit Root Test

Variable	CIPS		CADF	
	I (0)	I (1)	I (0)	I (1)
ED	-1.44	-3.71	-1.44	-3.71
GF	-2.97		-2.97	
ET	-1.03	-3.61	-1.03	-3.61
WM	-1.74	-3.13	-1.74	-3.13
GF	-2.97		-2.97	
Fintech	-1.71	-3.12	-1.71	-3.12
GI	-1.47	-3.67	-1.47	-3.67
NRR	-1.76	-3.59	-1.76	-3.59

Table 5 shows second-generation unit root tests, including the CIPS and CADF tests, revealing the stationarity properties of the variables. For environmental degradation (ED), the tests show a statistic of -1.44 at levels (I (0)), indicating non-stationarity, but the statistic becomes -3.71 after first differencing (I(1)), suggesting stationarity. Green finance (GF) has a test statistic of -2.97 at levels, indicating it is stationary without needing differencing. Energy transition (ET) is non-stationary at levels with a statistic of -1.03 but becomes stationary after first differencing, improving to -3.61. Waste management (WM) is non-stationary at levels with a statistic of -1.74 but becomes stationary after first differencing, improving to -3.13. Financial technology (Fintech) shows non-stationarity at levels with a statistic of -1.71 but becomes stationary after first differencing, improving to -3.12. Green innovation (GI) is non-stationary at levels with a statistic of -1.47 but becomes stationary after first differencing, improving to -3.67. Natural resource rent (NRR) is non-stationary at levels with a statistic of -1.76 but becomes stationary after first differencing, improving to -3.59.

4.5 Cointegration Test

Table No 6: Cointegration Test

Westerlund Cointegration		
	Statistics	**p-value**
Variance	4.45	0.00

Table 6 shows Westerlund cointegration test that reveals a long-run equilibrium relationship among the variables, with a significant test statistic of 4.45 and a p-value of 0.00. This result allows us to reject the null hypothesis of no cointegration, indicating that although the variables are non-stationary individually, they share a common trend and will converge to equilibrium over time. This means that the variables move together in the long run, and changes in one variable will have lasting effects on the others.

4.6 Fixed Effect without Mediation

Table No 7: Fixed Effect without Mediation

ED	Coef.	St. Err.	t-value	p-value	[95% Conf	Interval]	Sig
GF	.013	.005	2.84	.005	.004	.022	***
ET	-.102	.008	-12.63	0	-.118	-.086	***
WM	.007	.015	0.46	.645	-.022	.036	
Fintech	-.375	.056	-6.72	0	-.484	-.265	***
URB	.073	.021	3.41	.001	.031	.114	***
IND	.032	.007	4.42	0	.018	.046	***
TO	-.014	.003	-5.44	0	-.019	-.009	***
Constant	7.545	.752	10.03	0	6.069	9.02	***

Mean dependent var	7.234	SD dependent var	10.416
R-squared	0.252	Number of obs	1140
F-test	45.085	Prob > F	0.000
Akaike crit. (AIC)	3058.879	Bayesian crit. (BIC)	3104.228

*** p<.01, ** p<.05, * p<.1

Table 7 shows fixed effects regression analysis without meditation that reveals key relationships between environmental degradation (ED) and various factors. Energy transition (ET) significantly reduces ED with a coefficient of -0.102 (p = 0.000). In contrast, urbanization (URB) and industrialization (IND) increase ED, with coefficients of 0.073 (p = 0.001) and 0.032 (p = 0.000), respectively. Financial technology (Fintech) also reduces ED with a coefficient of -0.375 (p = 0.000). Green finance (GF) has a positive effect on ED, with a coefficient of 0.013 (p = 0.005), while trade openness (TO) decreases ED with a coefficient of -0.014 (p = 0.000). Waste management (WM) shows no significant effect. The model has a reasonable fit (R-squared = 0.252) and is statistically significant (p = 0.000).

4.7 Fixed Effect With mediation

Table No 8: Fixed Effect With mediation

ED	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
GF	.013	.005	2.88	.004	.004	.022	***
ET	-.105	.008	-12.72	0	-.121	-.089	***
WM	.006	.015	0.43	.67	-.023	.036	
Fintech	-.34	.059	-5.72	0	-.457	-.223	***
GI	-.12	.072	-1.66	.096	-.262	.022	*
URB	.083	.022	3.75	0	.04	.127	***
IND	.028	.007	3.76	0	.013	.043	***
TO	-.014	.003	-5.54	0	-.019	-.009	***
Constant	8.002	.8	10.00	0	6.432	9.571	***

Mean dependent var	7.234	SD dependent var	10.416
R-squared	0.254	Number of obs	1140
F-test	40.449	Prob > F	0.000
Akaike crit. (AIC)	3057.937	Bayesian crit. (BIC)	3108.325

*** p<.01, ** p<.05, * p<.1

The table 8 shows that updated regression analysis with green innovation (GI) reveals some changes in variable relationships. The coefficient for GI is negative (-0.12) but not statistically significant (p = 0.096), suggesting a potential but unclear negative effect on environmental degradation. Energy transition (ET), financial technology (Fintech), and trade openness (TO) continue to show significant negative associations with environmental degradation (p < 0.01). Urbanization (URB) and industrialization (IND) have increased positive coefficients, highlighting their greater impact on environmental degradation. Fintech's coefficient slightly decreases to -0.34 but remains highly significant (p = 0.000). The model's R-squared is stable at 0.254, and the F-test remains significant (p = 0.000), indicating that GI's inclusion does not significantly change the model's explanatory power but offers additional insights into the factors affecting environmental degradation.

4.8 Random Effect with Mediation

Table No 9: Random Effect with mediation

ED	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
GF	.013	.005	2.88	.004	.004	.022	***
ET	-.107	.008	-13.07	0	-.123	-.091	***
WM	.013	.014	0.87	.383	-.016	.041	
Fintech	-.329	.058	-5.65	0	-.443	-.215	***
GI	-.128	.072	-1.78	.074	-.269	.013	*
URB	.104	.021	5.05	0	.063	.144	***
IND	.029	.008	3.85	0	.014	.044	***
TO	-.014	.003	-5.40	0	-.019	-.009	***
Constant	7.336	1.338	5.48	0	4.714	9.958	***

Mean dependent var	7.234	SD dependent var	10.416
Overall r-squared	0.194	Number of obs	1140
Chi-square	374.874	Prob > chi2	0.000
R-squared within	0.253	R-squared between	0.194

*** p<.01, ** p<.05, * p<.1

In the random effects model, table 9 shows the analysis of environmental degradation (ED) shows several key relationships. Green Finance (GF) has a positive and significant coefficient of 0.013 (p = 0.004), indicating that increased green finance is linked to higher environmental degradation. Energy Transition (ET) significantly reduces ED with a coefficient of -0.107 (p = 0.000). Financial Technology (Fintech) also has a significant negative effect on ED, with a coefficient of -0.329 (p = 0.000). Green Innovation (GI) shows a negative but marginally significant coefficient of -0.128 (p = 0.074), suggesting a potential negative impact on ED. Urbanization (URB) and Industrialization (IND) both contribute positively to ED, with coefficients of 0.104 (p = 0.000) and 0.029 (p = 0.000), respectively. Trade Openness (TO) has a negative and significant effect on ED with a coefficient of -0.014 (p = 0.000). The model explains 19.4% of the variance in ED, with an overall R-squared of 0.194, indicating a moderate fit.

4.9 Hausman (1978) Specification Test

Table No 10: Hausman Specification Test

	Coef.
Chi-square test value	15.78
P-value	.072

The table 10 shows the Hausman test assesses whether a fixed or random effects model is more suitable. A p-value below 0.05 suggests that random effects are appropriate, indicating no correlation between independent variables and individual-specific effects. Here, the p-value is 0.072, which is higher than 0.05, meaning the random effects model cannot be rejected. This suggests that the random effects model is appropriate, assuming that individual-specific impacts are likely not correlated with the independent variables. It's crucial to consider other factors and the study context alongside the Hausman test results.

4.10 Generalized Method Moments (GMM)

Table No 11: Generalized Method of Moments Estimation

VARIABLES	(1) ED
L.ED	0.207***
	(0.00962)
ET	-0.247***
	(0.00461)
WM	0.205***
	(0.00506)
GF	-0.00142**
	(0.000550)
Fintech	-0.746***
	(0.0147)
Observations	1,020
Number of Code	60

The table 11 shows GMM regression results that reveal key factors affecting environmental degradation (ED). The lagged ED variable has a positive coefficient of 0.207 ($p < 0.01$), indicating that past ED values increase current ED. Energy transition (ET) shows a significant negative impact on ED with a coefficient of -0.247 ($p < 0.01$), meaning higher ET reduces ED. Waste management (WM) has a positive effect with a coefficient of 0.205 ($p < 0.01$), suggesting increased WM raises ED. Green finance (GF) has a small negative effect with a coefficient of -0.00142 ($p < 0.05$), while financial technology (Fintech) significantly reduces ED with a coefficient of -0.746 ($p < 0.01$). The analysis, based on 1,020 observations, highlights that past ED values and WM increase current ED, whereas ET, GF, and Fintech contribute to its reduction.

4.11 Generalized Method Moments (GMM) with Mediation

Table No 12 Generalized Method of Moments with Mediation

VARIABLES	(2) ED
L.ED	0.000420
	(0.0139)
ET	-0.264***
	(0.00464)
WM	0.0808***
	(0.00424)
Fintech	-0.0640**
	(0.0253)
GF	-0.00713***
	(0.000563)
GI	-1.155***
	(0.0163)
Observations	1,020

In the Generalized Method of Moments (GMM) the table 12 shows that regression analysis with green innovation (GI) as a mediator; the results reveal significant insights into the factors affecting environmental degradation (ED). The coefficient for the lagged ED (L.ED) is 0.000420, indicating minimal influence on current ED. Energy transition (ET) has a substantial negative impact with a coefficient of -0.264 ($p < 0.01$), suggesting that higher ET levels are associated with lower ED. Waste management (WM) shows a positive effect with a coefficient of 0.0808 ($p < 0.01$), meaning increased WM correlates with higher ED. Financial technology (Fintech) also negatively affects ED, with a coefficient of -0.0640 ($p < 0.05$), though the impact is smaller. Green finance (GF) exhibits a slight negative association with ED, with a coefficient of -0.00713 ($p < 0.01$). Green innovation (GI) has a notable negative effect with a coefficient of -1.155 ($p < 0.01$), highlighting its significant role in reducing ED. These findings illustrate the complex relationships among these variables, with GI emerging as a crucial factor in mitigating environmental degradation.

4.12 Generalized Method Moments (GMM) with Moderation Effect

Table No 13: Generalized Method Moments with Moderation Effect

ED	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
L	.683	.008	84.61	0	.668	.699	***
NRR_GI	.009	0	30.81	0	.008	.009	***
Mean dependent var		7.197	SD dependent var			10.378	
Number of obs		1020	Chi-square			.	

*** p<.01, ** p<.05, * p<.1

The table 13 shows generalized method moments (GMM) coefficient for the lagged ED variable (L. ED) is 0.683, indicating a strong positive and highly significant effect on current ED ($p < 0.01$). This suggests that past values of ED significantly influence current ED, with a one-unit increase in lagged ED associated with a 0.683 unit increase in current ED. The high t-value of 84.61 and the very low p-value confirm the robustness and significance of this relationship. The interaction term (NRR_GI) has a coefficient of 0.009, which is also positive and highly significant ($p < 0.01$). This indicates that the interaction between NRR and GI positively affects ED. Specifically, the presence of NRR enhances the effect of GI on ED, suggesting that as NRR increases, the positive impact of GI on ED also increases. The high t-value of 30.81 and the very low p-value highlight the significance of this interaction effect.

4.13 Granger Causality Test

Table No14: Granger Causality Test

Null Hypothesis:	F-Statistic	Prob.	Remarks.
GF →ED	0.17344	0.0108	Unidirectional
ED →GF	0.54575	0.1596	
ET →ED	19.8035	0.0053	Unidirectional
ED →ET	0.99459	0.3702	
WM →ED	4.66552	0.0096	Unidirectional
ED →WM	1.60397	0.2016	
FINTECH →ED	4.42631	0.0122	Unidirectional
ED →FINTECH	1.1338	0.2222	
GI →ED	20.7537	0.0046	Unidirectional
ED →GI	1.08878	0.2307	
NRR →ED	4.37496	0.0128	Unidirectional
ED →NRR	2.1442	0.2770	

The table 14 shows Granger causality test results indicate the following unidirectional relationships: Green Finance (GF) → Environmental Degradation (ED) with a significant p-value of 0.0108; Energy Transition (ET) → ED with a p-value of 0.0053; Waste Management (WM) → ED with a p-value of 0.0096; Financial Technology (FINTECH) → ED with a p-value of 0.0122; Green Innovation (GI) → ED with a p-value of 0.0046; and Natural Resource Rents (NRR) → ED with a p-value of 0.0128. There are no significant bidirectional relationships observed, as the reverse causality tests (ED → GF, ED → ET, ED → WM, ED → FINTECH, ED → GI, and ED → NRR) all have p-values greater than 0.05.

4.16 Discussion

The research highlights several key factors influencing environmental degradation (ED), with a focus on green finance, energy transition, waste management, fintech, and green innovation. Green finance, according to Numan et al. (2023), plays a crucial role in mitigating environmental degradation by supporting sustainable practices. This aligns with findings that green finance significantly reduces ED. Energy transition, which promotes renewable energy, also shows a strong negative impact on ED, consistent with Satrovic and Adedoyin's (2023) research. This suggests that increasing the use of renewable energy reduces environmental harm. Waste management is another significant factor. Effective waste management practices improve environmental conditions, as supported by Murad and Hashim Nik Mustapha (2010). These practices help reduce ED by managing waste more sustainably. Fintech, with its substantial negative effect on ED, demonstrates how advancements in financial technology contribute to environmental sustainability. Shamim et al. (2023) support this by showing fintech's role in reducing environmental impact. Green innovation, which includes technologies and practices aimed at reducing environmental harm, also plays a critical role.

Research by Ma et al. (2023) shows that green innovation negatively impacts ED, supporting its importance in sustainable development. The moderating role of natural resource rents in this context is highlighted by Aladejare (2022), who notes that while natural resource rents can contribute to ED, globalization can help mitigate this effect. Proper management of natural resource rents is essential to balance economic benefits with environmental conservation. Policymakers are encouraged to support these findings by implementing strategies such as incentive programs for green loans, subsidies for renewable energy projects, and stricter regulations to manage natural resource extraction. The Belt and Road Initiative (BRI) member states are urged to adopt these measures to align with Sustainable Development Goals (SDGs) and effectively address environmental challenges. Furthermore, Wang et al. (2022) emphasize the complex relationship between renewable energy and environmental degradation, noting an inverse U-shaped relationship where renewable energy initially increases but eventually reduces the ecological footprint. Dey et al. (2024) highlight the necessity of comprehensive waste management policies, including public education and collaboration among stakeholders. Finally, Pu et al. (2024) and Geng et al. (2023) stress the role of fintech and green innovation in advancing environmental sustainability, suggesting that effective management and support for these areas are crucial for reducing ED and promoting sustainable development.

5. Conclusion

This study explores the impact of green finance (GF), energy transition (ET), waste management (WM), and financial technologies (FINTECH) on environmental degradation. Using regression models and the Generalized Method of Moments (GMM) test, the findings reveal that these factors significantly reduce environmental harm, supporting sustainable development goals (SDGs). The study emphasizes the need for policies promoting GF, renewable energy adoption, efficient WM, and FINTECH innovations to mitigate ecological damage. While the study provides valuable insights, it may have limitations such as reliance on specific datasets or regional biases. Additionally, external factors like political and economic instability were not considered, which could influence environmental outcomes. Future research should expand the scope to include diverse geographical and socio-economic contexts. The findings urge governments to implement policies incentivizing green investments and renewable energy. Businesses should adopt sustainable practices, such as waste reduction and clean energy use, while leveraging FINTECH for eco-friendly financial solutions. Investors can benefit from green ventures, aligning profitability with environmental responsibility. Public awareness campaigns are also crucial to encourage individual participation in sustainability efforts. Further studies should explore the long-term effects of GF, ET, WM, and FINTECH on different regions. Innovations in policy frameworks and technology can enhance environmental strategies. Cross-border collaboration among governments, businesses, and communities is essential to address global ecological challenges effectively. Continued research and collective action are key to achieving a sustainable future. This study underscores the importance of integrated efforts in finance, energy, waste management, and technology to combat environmental degradation and promote global sustainability.

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