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Navigating the Influence of Financial, Economic and Technological Factors on Environmental Sustainability: Insights from MMQR Approach

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ABSTRACT

This study investigates the effect of financial, economic and technological factors on environmental sustainability in 63 economies using a panel data spanning from 2002 to 2022. For data estimation cross-sectional dependence test, slope heterogeneity, CIPS panel unit root test, Pedroni, Kao and Westerlund cointgeration tests and MMQR approach are used. The analysis shows that GDP is positively and GDP^2 is negatively linked to the CO_2 emissions and ecological footprint at different quantiles suggesting that EKC is holds in the panel of 63 countries. In addition, green energy, green finance, technological innovation and regulatory framework are improving the environmental quality. Lastly, industrial activities and FDI is found to be positively linked to the CO_2 emissions and ecological footprint at different quantiles. Keeping in view the study outcomes, it is concluded that financial, economic, and technological factors significantly impact environmental sustainability. Economic growth often conflicts with sustainability, and technological advancements can mitigate or exacerbate environmental harm, highlighting the need for balanced, inclusive, and sustainable policies.

Keywords: *GDP, Technological Innovation, FDI, Industrialization, Regulatory Framework, Green Energy, Green Finance*

INTRODUCTION

Globally, environmental sustainability is essential to achieving sustainable development goals. Therefore, health, clean energy, food security, life below the water, prosperity, and long-term growth—all of which are important SDG deliverables—are at risk due to the growing trend of environmental degradation (Awosusi et al., 2021). The EKC curve is widely used to analyse the relationship between GDP and environmental degradation. According to the Environmental Kuznets Curve theory, environmental issues will first worsen as an economy grows but will gradually subside. It has been noted that the correlation between income and pollution is positive once more for high incomes, or perhaps the environmental Kuznets curve is U-shaped. The U-curve illustrates how population pressure, widespread production methods, and excessive use and exploitation of natural resources are all linked to environmental. There have also been claims that people who are wealthier tend to advocate for more stringent environmental regulations, which could lead to a correlation between emissions and per capita income as well as the impact of per capita income on environmental standards or pollution taxes, for instance. Third, the structural effect must be taken into account. An economy's sectorial composition often follows a time pattern where a country's big agricultural sector is followed by an industrialization phase, de-industrialization, and a growing service sector (Bozatli & Akca, 2024; Tenaw & Beyene, 2021).

On the other hand, green energy is essential for enhancing the quality of the environment. Green energy sources, such as solar, hydro, and wind, can be used as a replacement to address these environmental problems. Renewable energy can meet energy production needs and improve environmental quality. It also doesn't pollute the environment by substituting nonrenewable technologies and doesn't deteriorate it (Akella et al., 2009). Nonetheless, there are a number of possible advantages to using more renewable energy, such as lowering greenhouse gas emissions, diversifying energy sources, and lowering reliance on the market for fossil fuels. Furthermore, carbon-intensive energy sources can be replaced by renewable energy initiatives. Because the renewable energy sector requires a greater amount of labor, expanding the supply of renewable energy could boost employment by generating opportunities in new "green" technology (Belaïd & Zrelli, 2019). Furthermore, green finance has increased as a result of investors' growing awareness of the benefits of green energy for environmental welfare (Gagnon et al., 2020). Because sustainable company models have lower profits volatility, green financing reduces credit risk. Lenders might profit from lower loan loss provisions and capital requirements when borrowers pose less credit risk. This aids in achieving environmental objectives (Umar et al., 2020).

Additionally, the process of globalization together with deregulation has expanded both the capability and adaptability of FDI during while also accelerating FDI transfer patterns. FDI serves as the fundamental building block for economic development and employment generation and technology advancement and improved living conditions in developing countries (Xu et al., 2019). FDI has three different mechanisms which affect the ED dimension. The scale-effect demonstrates that large-scale increases in industrial production following multinational FDI operations lead to environmental degradation because they increase total pollution levels (Pao and Tsai, 2011). The environmental effects of FDI exist in multiple patterns that are difficult to predict. Furthermore, degradation of the global environment is largely caused by industrial operations. Although new technology and environmental regulations are lessening the environmental effect per unit produced in industrialized nations, industrial operations and rising demand continue to strain the environment and the base of natural resources. A double environmental effect is taking place in developing nations: long-standing environmental issues like soil erosion and deforestation are still mostly unresolved. Simultaneously, additional issues associated with industrialization are emerging, including increased greenhouse gas emissions, pollution of the air and water, increasing waste volumes, desertification, and pollution from chemicals (Ahuti, 2015). Industrialization, while pivotal for economic growth, might have dual implications. On one hand, rapid industrial activities can lead to increased emissions and environmental degradation.

Businesses may be encouraged to invest more in and conduct research and development of clean production technology by strict environmental legislation. Thus, technological innovation is stimulated, production efficiency is improved, and industrial structures can be upgraded and transformed more easily (Jiang et al., 2021). Environmental regulations also help companies use resources more effectively, lower production costs, and increase resource economic efficiency, all of which contribute to the long-term growth of the economy (Yang et al., 2021). The economy may be impacted by some environmental restrictions, nevertheless, as they may raise production costs for companies, lowering their profitability and maybe creating operational challenges for some (Shi and Huang, 2019). Strict environmental rules may also result in the creation of new environmental sectors and the loss of jobs in labor-intensive industries, which would have an impact on the labor market. In conclusion, sensible and scientific environmental rules can support technological innovation, the modernization of industrial and economic structures, and the effective use of resources, all of which contribute to the economy's high-quality growth. A positive relationship between environmental protection and economic development can be achieved by implementing environmental regulations while taking economic development needs into account and avoiding excessively strict regulations that could make business operations unnecessarily difficult (Ahmed et al., 2022).

Understanding the implications of financial, economic and technological dynamics on environmental sustainability is crucial for formulating effective policy interventions. In essence, this research seeks to offer a comprehensive understanding of how green finance, green energy, industrialization, FDI, technological advancements, GDP, and regulatory frameworks interact to shape the environmental sustainability. By delving into these multifaceted interactions, the study aspires to contribute significantly to the discourse, guiding policy decisions and future research towards sustainable development in the region. The findings of this research are poised to inform policy decisions and aid in the formulation of strategies that balance economic development with environmental stewardship.

LITERATURE REVIEW

Different studies analyzed the financial, economic and technological factors of environmental sustainability such as Ibrahim et al., (2022) examined the impacts of renewable energy non-renewable energy, rental total resources, rapid growth of population, human being's capital including financial inclusion on quality environment in the Sub-Saharan Africa (SSA) under terms and conditions roles pertaining to technological progression and levels of income sources. Their study revealed that renewable energy is imperative to improve the environmental quality in SSA. Samour et al., (2023) showed that electricity energy renewable and human beings' capital play significant role for the environment sustainability. Whereas; consumption of electricity, economic progress and process of industrialization create impediments to promote environmental sustainability. According to Mohammed et al., (2023), the EU's economic development has advanced to a point where environmental benefits are a direct result of economic expansion. This study sheds light on how well environmental regulations work in the EU 27 nations to reduce degradation and encourage green growth.

Yunus et al., (2023) validate that green innovation, investments in clean energy, and education contribute to long-term environmental sustainability, albeit short-term effects vary. Therefore, governments in heavily polluted economies should boost funding in education, clean energy, and technology to reduce CO2 emissions. Research conducted by Jijian et al. (2021) confirmed that CO2 emissions show a positive connection with foreign direct investment in BRICS countries but this link was statistically insignificant. Research findings indicate FDI does not produce equally significant effects on environmental status. Chang et al., (2023) evaluate the impacts of environmental regulation (ER) on the relationship between green innovation and CO_2 emissions reduction in China utilizing data from 30 provinces between 2003 and 2019. The findings indicate that environmental restrictions enhance the effect of green knowledge innovation (GKI) on reducing CO_2 emissions, but have a less significant impact on green process innovation.

Zhongping et al., (2023) showed that investing in green finance positively impacts both economic and environmental performance. Privatization positively affects long-term economic success but negatively impacts environmental performance. Ali et al., (2023) found that energy transition and diversification, technical innovation, and foreign direct investment are all negatively associated with CO_2 emissions at all levels. Digital finance inclusion, energy consumption, and economic expansion are the main factors causing environmental degradation in the E-7 region. Udegha et al., (2023) found that the results align with the EKC theory, suggesting that GFN, fintech, and energy innovation contribute to environmental sustainability. Conversely, natural resource rent and economic expansion negatively affect environmental quality. Bakhsh et al., (2024) conducted a study examining how financial inclusion and digitization in China could influence environmental sustainability. The study takes a holistic approach, using wavelet analysis, Granger causality in quantiles, quantile-on-quantile regression, and robustness tests. It shows that in China, financial inclusion, digitization, and environmental sustainability are significantly positively correlated. The results highlight how important the financial industry and technical innovation are to guiding the country towards sustainable growth.

DATA AND METHODOLOGY

This study examines the effect of economic, technological and financial factors on environmental sustainability using a panel dataset of 63 economies from 2002 to 2022. The study measured the environmental sustainability using CO_2 emissions and ecological footprint. The economic factors used in a model are GDP, GDP^2, and green energy. The financial factors used in a model are green finance and foreign direct investment and technological factors added in a model are industrialization and technological innovation. The data of variables CO_2 emissions, green finance, green energy, industrialization, FDI, technological advancement, and GDP is taken from WDI indicators while the data of ecological footprints is taken from global footprint network. Lastly, the data of regulatory framework is taken from World governance indicators. Given the variables and the objectives of the study, the model can be formulated as:

$$CO_{2it} = \beta_o + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_3 GE_{it} + \beta_4 GF_{it} + \beta_5 FDI_{it} + \beta_6 TA_{it} + \beta_7 IND_{it} + \beta_8 RF_{it} + u_{it} \quad (1)$$

$$EF_{it} = \beta_o + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_3 GE_{it} + \beta_4 GF_{it} + \beta_5 FDI_{it} + \beta_6 TA_{it} + \beta_7 IND_{it} + \beta_8 RF_{it} + u_{it} \quad (2)$$

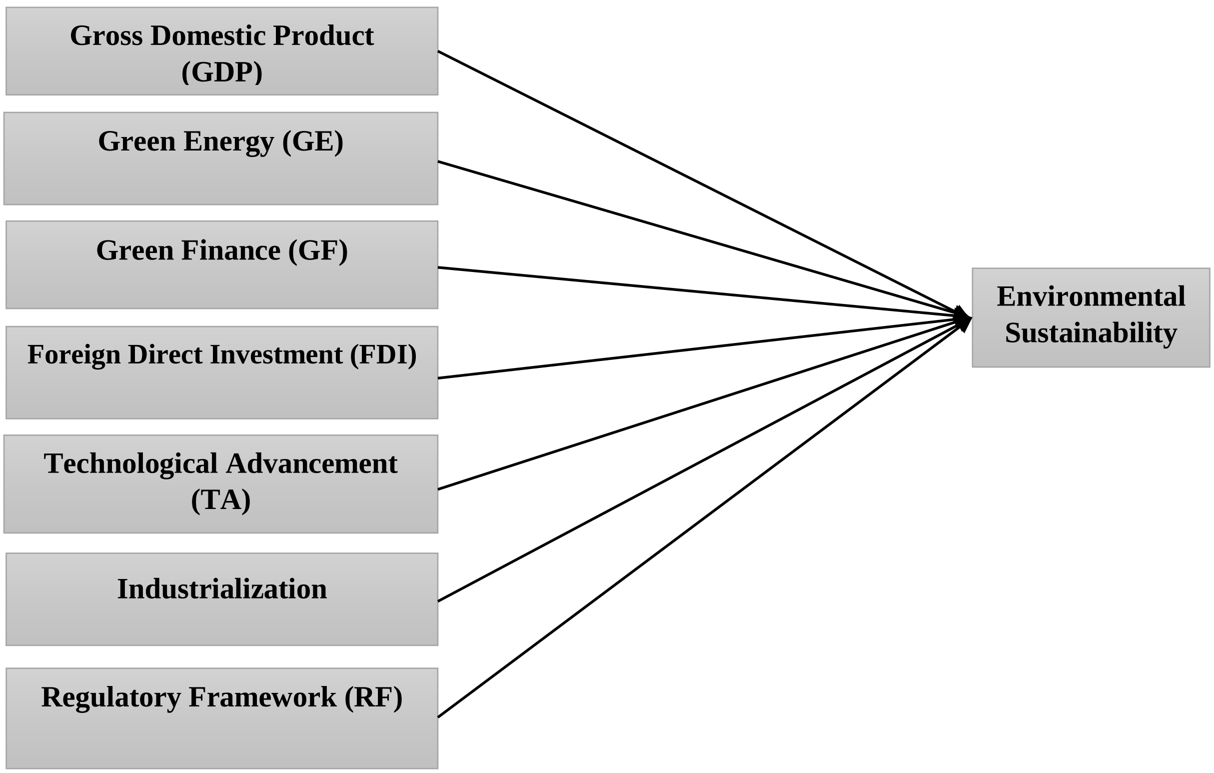
Where CO_2 is carbon dioxide emissions, EF indicates ecological footprints, GDP represents gross domestic product, GDP^2 is the square of GDP, GE specifies green energy, GF indicates green finance, FDI represents foreign direct investment, TA indicates technological advancement, IND represents industrialization, RF is the regulatory framework and u_{it} is the error term.

Table 1: Measurement of Variables

Variable Name	Symbol	Measurement	Source
Ecological Footprints	EF	Natural log of Ecological footprint per capita	GFN
CO2 emissions	CO2	Natural log of CO2 emissions matric tones	WDI
Green Finance	GF	Natural log of Renewable energy consumption (% of total final energy consumption)	WDI
Green energy	GE	Natural log of Renewable energy consumption (% of total energy consumption)	WDI
Industrialization	IND	Natural log of Industry (including construction), value added (% of GDP)	WDI
Gross domestic product	GDP	Natural log of GDP current US dollars	WDI
Technological Advancement	TA	Natural log of Number of patent applications	WDI
Regulatory Framework	RF	Natural log of Regulator quality	WGI
Foreign Direct Investment	FDI	Natural log of Net Inflows of FDI (% of GDP)	WDI

Note: WDI = World development indicators, WGI = World governance indicators, GFN = Global footprint network

Figure 1: Conceptual Framework



Data Estimation Techniques

For data analysis different econometric techniques are applied such as the cross-sectional dependence test is applied to check the interconnectedness of the countries. Slope homogeneity test to check the heterogeneity issue, CIPS and CADF tests for panel unit root, Pedroni and Westerlund tests to check the cointegration and MMQR approach for the long-run parameters estimations. Lastly, DH causality test is used to check the causal relationship.

Cross Sectional Dependence (CSD)

The first stage of the panel data analysis was testing the CSD between the series. This test was carried out to find and address the unit root and CSD issues in the data set. The CSD must be handled with accuracy and precision because it is linked to economic unions, financial shocks, demand shocks, supply shocks, pandemic diseases, globalization, and trade conflicts. If disregarded, it might produce skewed conclusions for stationarity and cointegration (Khan et al., 2020). To address the CSD issue, the cross-sectional dependence test was used. The CSD statistics can be represented as follows:

$$CSD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=0}^{N-1}\ \sum_{i=0}^{N-1} P_{ij}\right) N(0,1) \qquad (3)$$

Where; P_{ij} denotes the cross-sectional correlation of error between j and i. T and N represent time horizon and cross-sections, respectively. The selection of this approach is due to the dataset size, i.e., a smaller number of cross-sections compared to the time period (Nathaniel et al., 2021).

Unit Root Test

The 1st generation unit root methods are not appropriate if the CSD problem is found since they are unable to address the CSD issue. The Pesaran (2003) cross-sectional augmented Dickey-Fuller (PCADF) and Pesaran (2007) cross-sectional augmented IPS (CIPS) unit root tests are used as second-generation tests to identify CSD problems. The assumption of cross-sectional independence serves as the foundation for traditional or first-generation panel unit root tests (CSI). Nonetheless, the second-generation unit root tests support the CSD assumption for the data series. The equation of PCADF test is shown below:

$$\Delta y_{it} = \alpha_i + b_i y_{i},_{t-1} + c_i y_{t-1} + \sum_{j=0}^{n} \delta_{ij} \Delta y_{i,i-j} + e_{it} \qquad (4)$$

where Δy displays the cross-sectional outcome variable averages at initial differences, while y displays the cross-sectional outcome variable averages at lagged levels. The estimated t-statistic from Equation (5) is then used to calculate the PCIPS statistic, which is defined as:

$$PCIPS = N^{-1} \sum_{i=1}^{N} CADF_i \qquad (5)$$

MMQR Approach

Each quantile's distributional and heterogeneous impacts are examined using the quantile regression (QR) estimator. This method was created by Bassett & Koenker (1978) and is commonly used to find the conditional median of several answer quantiles. Consequently, the quantile-on-quantile regression (QQR) can be employed to characterize the weak link between the conditional means of two indicators and is more sensitive to the existence of outliers in estimations (Binder & Coad, 2011). However, Machado & Silva (2019) suggest an enhanced QQR that takes fixed effects into account, called methods of moment's quantile regression (MMQR). This method works well for identifying the impact of conditional heterogeneity on the covariance of CO2 emission drivers. This method is also helpful when the model is firmly rooted in individual effects and includes endogenous explanatory factors. The conditional quantiles Qy(τ|X) for the location-scale variation framework are shown as follows:

$$Qy_{it}(\tau / X_{it}) = \alpha(\tau)' X_{it} + \beta_i \quad \text{I = 1,….., N, t = 1,….., T} \qquad (6)$$

Y_{it} is the symbol for the predicted variable (LICDE), X_{it} outline the repressors, a(τ) stands for the unknown coefficients, βi refers to the individual effects.

Descriptive Analysis

Table 2 presents the descriptive statistics of selected variables of 63 countries from 2002 to 2022. The results show that the mean values of CO_2 emissions, EF, GDP, GE, GF, FDI, TA, IND and RF are 10.381, 1.196, 25.220, 3.109, 3.706, 0.948, 6.371, 3.255 and 0.212, respectively. Similarly, the maximum values of CO_2 emissions, EF, GDP, GE, GF, FDI, TA, IND and RF are 16.265, 17.617, 30.454, 4.588, 5.305, 5.457, 14.264, 4.306 and 2.040, respectively. In contrast, the minimum values of CO_2 emissions, EF, GDP, GE, GF, FDI, TA, IND and RF are 6.482, -0.549, 21.057, -1.171, -0.711, -6.918, 0.717, 2.244 and -1.995, respectively. The distributions of variables CO_2 emissions, EF, GDP, RF and TA are positively skewed whereas GE, GF, FDI and IND have negatively skewed distribution. In addition, kurtosis values of CO_2 emissions, EF, GE, GF, FDI, TA and IND indicate leptokurtic distribution while GDP and RF have a platykurtic distribution. Lastly, Jarque-Bera test statistic of variables CO_2 emissions, EF, GDP, GE, GF, FDI, TA, IND and RF are statistically significant indicting the normal distribution of variables.

Table 2: Descriptive Statistics

Variables	CO_2	EF	GDP	GE	GF	FDI	TA	IND	RF
Mean	10.381	1.196	25.220	3.109	3.706	0.948	6.371	3.255	0.212
Median	10.276	0.899	24.969	3.206	3.829	0.990	6.382	3.258	0.068
Maximum	16.265	17.617	30.454	4.588	5.305	5.457	14.264	4.306	2.040
Minimum	6.482	-0.549	21.057	-1.171	-0.711	-6.918	0.717	2.244	-1.995
Std. Dev.	1.731	2.194	1.755	1.033	0.889	1.158	2.224	0.296	0.921
Skewness	0.456	6.436	0.378	-0.743	-0.703	-0.596	0.346	-0.160	0.183
Kurtosis	3.220	48.074	2.539	3.555	3.820	6.809	3.541	3.659	2.060
J.B.	48.429	121.70	43.174	138.62	146.07	878.17	42.56	29.557	56.055
Prob.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Correlation Analysis

Table 3 exhibits that CO_2 emissions (CO_2E) are directly correlated with the GDP (0.802), industrialization (0.228) while CO_2E are negatively correlated with the green energy (-0.476), green finance (-0.421), FDI (-0.114), technological innovation (-0.826), and regulatory framework (-0.245). Furthermore, ecological footprints are positively correlated with the GDP (0.173), FDI (0.167) and industrialization (0.055) whereas ecological footprints are negatively correlated with the green energy (-0.168), green finance (-0.387), technological innovation (-0.168), and regulatory framework (-0.446).

Table 3: Correlation Analysis of Variables

	CO_2	EF	GDP	GE	GF	FDI	TA	IND	RF
CO_2	1.000	0.134	0.802	-0.476	-0.421	-0.114	-0.826	0.228	-0.245
EF	0.134	1.000	0.261	-0.168	-0.387	0.167	-0.168	0.055	-0.446
GDP	0.802	0.261	1.000	-0.313	0.479	-0.107	0.778	0.027	0.422
GE	-0.476	-0.168	-0.313	1.000	-0.292	-0.104	-0.400	-0.151	-0.266
GF	-0.421	-0.387	0.479	-0.292	1.000	0.128	0.494	-0.200	0.703
FDI	-0.114	0.167	-0.107	-0.104	0.128	1.000	-0.106	-0.119	0.226
TA	-0.826	-0.168	0.778	-0.400	0.494	-0.106	1.000	0.192	0.278
IND	0.228	0.055	0.027	-0.151	-0.200	-0.119	0.192	1.000	-0.308
RF	-0.245	-0.446	0.422	-0.266	0.703	0.226	0.278	-0.308	1.000

CSD and Slope Homogeneity Test (SH)

Table 4 is presenting the results of Pesaran's CSD test. The outcomes of Pesaran CD test shows that all the variables CO_2 emissions, EF, GDP, GE, GF, FDI, TA, IND and RF have statistically significant test statistic. Therefore, it is suggested that the null hypothesis of no cross-sectional dependence is rejected. It is proposed that the variables CO_2 emissions, EF, GDP, GE, GF, FDI, TA, IND and RF are cross-sectionally dependent.

Table 4: CSD Test Estimates

Variables	CSD Test	Prob.
CO_2	13.09061***	0.0000
EF	17.99420***	0.0000
GDP	174.0892***	0.0000
GE	292.3319***	0.0000
GF	48.01053***	0.0000

FDI	16.08402***	0.0000
TA	4.551184***	0.0000
IND	24.08348***	0.0000
RF	5.433533***	0.0000

Note: **, **, *** shows p-values <0.10, < 0.05 and 0.01, correspondingly*

To test the slope homogeneity, we have applied Pesaran & Yamagat (2008) and Blomquist & Westerlund (2013) tests. Table 6.4 displays the outcomes of the tests. The outcomes show that delta and adj delta test values are found to be statistically significant at 1 percent level therefore, the H_o of no slope heterogeneity is rejected. It is proposed that there is heterogeneity issue in the CO_2 emissions and ecological footprints models.

Table 5: Slope Homogeneity Test

DV	**Pesaran & Yamagata (2008)**		**Blomquist & Westerlun (2013)**	
	Δ	**Prob.**	**Adj Δ**	**Prob.**
CO_2	21.666	0.0000	28.662	0.0000
EF	17.873		23.644	

Note: **, **, *** designates p-values <0.10, < 0.05 & 0.01, individually*

Unit Root Tests

Given the CSD and slope heterogeneity issues, the 2nd generation unit root test is reliable to test the data stationarity. For a given purpose, cross sectional IPS test (CIPS) is employed. Table 6 shows that the variables CO_2 emissions, ecological footprints, green energy, green finance, technological innovation, industrialization and regulatory framework are stationarity at 1st difference I (1) while the variables GDP and FDI are stationarity at order zero I (0) suggesting the mixed integration order in a model.

Table 6: Second Generation Panel Unit Root Test (CIPS)

Variables	**Without Trend**		**Results**
	Level	**1st Difference**	
CO_2	-1.627	-4.116***	I (1)
EF	-1.614	-4.789***	I (1)
GDP	-3.218***	-3.847***	I (0)
GE	-1.982	-3.961***	I (1)
GF	-1.607	-3.665**	I (1)
FDI	-2.728***	-5.156***	I (0)
TA	-1.889	-4.202***	I (1)
IND	-1.622	-3.817***	I (1)
RF	-1.978	-4.514***	I (1)

Note: **, **, *** designates p-values <0.10, < 0.05 & 0.01, correspondingly*

Panel Co-integration Analysis

Table 7 reports the outcomes of all these three tests. The outcomes show that Pedroni test including Phillips-Perron test, Modified Phillips-Perron test and ADF tests have statistically significant test statistic values of CO_2 emissions and ecological footprint models. Similarly, Kao tests including Dickey-Fuller test, ADF test and Modified Dickey-Fuller test tests have statistically significant test statistic values of CO_2 emissions and ecological footprint models. Lastly, Westerlund variance ratio of both models is also statistically significant. The outcomes of all three tests suggest the presence of long-run cointegration among variables in models.

Table 7: Outcomes of Co-integration Tests

Test	CO_2	EF
Pedroni Test		
Phillips-Perron test	-10.1019***	-10.8114***
Modified Phillips-Perron test	9.5482***	8.0005**
Augmented Dickey-Fuller test	-9.2459***	-12.0580***
Kao Test		
Dickey-Fuller test	3.1350**	-1.7997**
Augmented Dickey-Fuller test	3.8797***	-0.1538
Modified Dickey-Fuller test	2.9419**	1.9992**
Westerlund Test		
Variance Ratio	-4.4797***	-1.3773*

Note: **, **, *** specifies p-values <0.10, < 0.05 & 0.01, individually*

Method of Moments-Quantile Regression (MMQR) Results

This section presents the MMQR estimates of the effect of financial, economic and technological factors on environmental sustainability in the panel of 63 countries. The MMQR estimates show that the variable GDP is directly and significantly related to the CO_2 emissions and ecological footprints through different quantiles. The magnitude and significance level vary through the lower to upper quantiles. The coefficient of GDP suggests that a 1% increase in GDP lead to increase in CO_2 emissions by 0.402%, 0.270%, 0.174%, 0.392%, 0.596% and 0.843% respectively and 0.756%, 0.007% 0.762%, 0.760%, 0.756% and 0.742% increase in EF, respectively from location, scale, Q25-Q90. In contrast, GDP^2 is negatively and significantly related to the CO_2 emissions and ecological footprints through different quantiles. These findings point out that the EKC curve is hold in the panel of 63 countries that states that at the initial level of development increase in GDP lead to deteriorate the environmental quality while after a certain point it led to improve the environmental quality. The EKC framework was also validated by the studies of Bozatli & Akca (2024) and Tenaw & Beyene (2021). On the other hand, the findings also show that green energy is negatively and significantly related to the CO_2 emissions and ecological footprints through different quantiles. The coefficient of GE suggests that a 1% increase in GE lead to decrease in CO_2 emissions by -0.316%, -0.043% -0.352%, -0.318%, -0.286% and -0.247% respectively and -0.040%, 0.108%, -0.119%, -0.091%, -0.034% and -0.170%, decrease in EF, respectively from location, scale, Q25-Q90. These findings suggest that a clean workplace with lower greenhouse gas emissions is ensured when light, heat, ventilation, or motion are produced utilizing clean and renewable energy sources for various economic operations. Utilizing renewable energy encourages the development and preservation of natural resources. By eliminating the effects of greenhouse gas emissions from the atmosphere, this lessens environmental deterioration. The negative relationship between GE and ED was also validated by Iram et al., (2024) and Asghar et al., (2024).

Green finance also plays imperative role in promoting environmental sustainability. The findings display that green finance is negatively and considerably related to the CO_2 emissions and ecological footprints through different quantiles. The coefficient of GF suggests that a 1% increase in GF lead to decrease in CO_2 emissions by -0.174%, -0.094%, -0.252%, -0.177%, -0.107%, and -0.021%, respectively and -0.413%, -0.298%, -0.196%, -0.273%, -0.431%, and -0.993%, decrease in EF, respectively from location, scale, Q25-Q90. It implies that the availability of green finance expands an economy's financial resources and strengthens economic actors' ability to adopt ecologically friendly practices. This stops environmental deterioration and lowers greenhouse gas emissions (Xiong & Sun, 2023). The negative relationship between GF and ED was also validated by Asghar et al., (2024), and Chin et al., (2024).

In contrast, the findings show that foreign direct investment is positively and significantly related to the CO_2 emissions (Q75th-Q90th quantile) and ecological footprints (location, Q50th, Q75th and Q90th quantile) . The coefficient of FDI suggests that a 1% increase in FDI lead to increase in CO_2 emissions by 0.017%, 0.011%, 0.008%, 0.017%, 0.025%, and 0.034%, respectively and 0.037%, 0.014%, 0.025%, 0.035%, 0.049%, and 0.060% increase in EF, respectively from location, scale, Q25-Q90. The findings validate the scale effect and population heaven hypothesis which states that because of the impact of FDI on economic activity, higher levels of economic liberalization may lead to an increase in carbon dioxide emissions (Hamid et al., 2021). The positive effect of FDI on ED was also validated by Sabir et al., (2020) and Nadeem et al., (2020). In contrast, the outcomes display that technological innovation is adversely and significantly connected to the CO_2E and ecological footprints through different quantiles. The coefficient of TA suggests that a 1% increase in TA lead to decrease in CO_2E by -0.103%, -0.059%, -0.101%, -0.146%, and -0.200%, respectively and -0.139%, -0.107%, 0.061%, -0.089%, -0.145%, and -0.348%, decrease in EF, respectively from location, scale, Q50-Q90. These results suggest that technological innovation promotes environmental protection by reducing the amount of carbon emissions in the ecosystem and preserving ecological balance by regulating the waste released into the environment (Adebayo et al., 2021; Anwar & Malik, 2021).

Table 7: MMQR Results

Variables	Location	Scale	Q25	Q50	Q75	Q90
Dependent Variable: CO^2 Emissions						
GDP	0.402*	0.270**	0.174	0.392*	0.596**	0.843***
GDP^2	-0.719*	-0.612**	1.235***	-0.743*	-0.281**	-0.280**
GE	-0.316***	-0.043***	-0.352***	-0.318***	-0.286***	-0.247***
GF	-0.174***	-0.094***	-0.252***	-0.177***	-0.107***	-0.021**
FDI	0.017	0.011	0.008	0.017	0.025*	0.034*
TA	-0.103***	-0.059***	0.053***	-0.101***	-0.146***	-0.200***
IND	0.643***	0.085**	0.572***	0.640***	0.704***	0.781***
RF	-0.381***	0.026	-0.403***	-0.382***	-0.363***	-0.339***
C	-6.698	-2.988*	-4.179	-6.583**	-8.839***	-11.576***
Dependent Variable: Ecological Footprints						
GDP	0.756***	0.007	0.762***	0.760**	0.756**	0.742**
GDP2	-1.082*	0.388	-1.365	-1.264*	-1.059***	-0.328**
GE	-0.040***	-0.108**	-0.119*	-0.091***	-0.034**	-0.170***
GF	-0.413**	-0.298***	-0.196*	-0.273**	-0.431***	-0.993***
FDI	0.171*	0.144	0.065	0.103*	0.179**	0.451**
TA	-0.139**	-0.107***	0.061**	-0.089**	-0.145***	-0.348***
IND	0.759**	0.701***	0.246**	0.429***	0.799***	2.123***
RF	-0.727***	-0.184*	-0.592***	-0.640***	-0.738*	-1.085***
C	-14.267	-4.737	-10.807	-12.039	-14.543	-23.480

Note: **, **, *** designates p-values <0.10, < 0.05 & 0.01, correspondingly*

Industrial activities encourage the use of energy that can lead to degrade the environment. The outcomes display that industrialization is directly and considerably linked to the CO_2 emissions and ecological footprints through different quantiles. The coefficient of IND suggests that a 1% increase in IND lead to increase in CO_2E by 0.643%, 0.085%, 0.572%, 0.640%, 0.704%, and 0.781%, respectively and 0.759%, 0.701%, 0.246%, 0.429%, 0.799%, and 2.123%, increase in EF, respectively from location, scale, Q25-Q90. It recommends that more industrial activities in an economy require more energy to run the heavy machinery that may lead to increase the CO_2 emissions in the atmosphere. These results are similar to the findings of the studies by Li & Lin (2015) and Liu & Bae (2018). Lastly, strong regulatory framework is essential to protect the environment of any country. The findings show that regulatory quality is negatively and significantly related to the CO_2 emissions and ecological footprints through different quantiles. The coefficient of RF suggests that a 1% increase in RF lead to decrease in CO_2 emissions by -0.381%, -0.403%, -0.382%, -0.363%, and -0.339%, respectively from location, Q25-Q90 and -0.727%, -0.184%, -0.592%, -0.640%, -0.738%, and -1.085%, decrease in EF, respectively from location, scale, Q25-Q90. These results validate the Porter hypothesis, which holds that well-crafted environmental regulations promote green innovation and support environmental sustainability. Despite the widespread belief that environmental rules will compel businesses to adopt green, environmentally friendly solutions, the opposite may also happen because of the expenses associated with compliance and funding (Kesidou & Wu, 2020). These results were also found by Saqib et al., (2022) and Addai et al., (2024).

CONCLUSIONS AND RECOMMENDATIONS

This study analyzed the effect of financial, economic and technological factors on environmental sustainability in 63 economies using a panel data spanning from 2002 to 2022. The estimates of CSD test shows that CO_2E, EF, GDP, GE, GF, FDI, TA, IND and RF have statistically significant test statistic. Therefore, it is suggested that the null hypothesis of no cross-sectional dependence is rejected. It is proposed that the variables CO_2 emissions, EF, GDP, GE, GF, FDI, TA, IND and RF are cross-sectionally dependent. Pesaran & Yamagat (2008) and Blomquist & Westerlund (2013) tests proposed that there is heterogeneity issue in the CO_2 emissions and ecological footprints models. Panel CIPS test shows that the variables CO_2 emissions, ecological footprints, green energy, green finance, technological innovation, industrialization and regulatory framework are stationarity at 1^{st} difference I (1) while GDP and FDI are integrated at order zero I (0). Westerlund, Pedroni and Kao tests suggests the existence of long-run cointegration. The MMQR estimates show that the variable GDP is positively while GDP^2 is negatively and substantially connected to the CO_2E and ecological footprints, validating the EKC theory. The findings also display that technological innovation, regulatory framework, green energy and green finance are negatively and considerably connected to the CO_2E and ecological footprints. On the other hand, the findings display that foreign direct investment and industrialization are positively and considerably associated to the CO_2E and ecological footprints. Therefore, keeping in view the findings, it is concluded that green energy, technological innovation, regulatory framework and green finance is playing important role in promoting environmental sustainability. Green finance can promote cleaner energy solutions and environmentally friendly manufacturing processes. Furthermore, green finance enables industries to adopt greener practices, ultimately contributing to sustainable development.

The study recommends the following suggestions to promote the environmental sustainability by considering the outcomes of the study:

1. Foreign capital inflows are the main driver of economic growth, although they also cause environmental deterioration. Therefore, in order to boost their production and improve the environment, countries must create environmental rules and entrance requirements for foreign inflows. In order to introduce green and ecologically friendly technology into a nation, stringent environmental restrictions must be put in place, even though FDI inflows should be encouraged.
2. Countries should firmly remove outdated manufacturing technologies and the governments of these nations should support the development of green industries and environmentally friendly technologies by offering green credit for the industrialists as environmental degradation can be reduced by speeding up the transformation and improvement of the industrial structure. The

transformation and improvement of the industrial structure include the transition from low to high value-added and the transition from high to low energy consumption.

3. Investment in research and development is essential to promote and develop the greener and energy efficient technologies.
4. To enable citizens to switch from energy-intensive equipment to energy-efficient ones, governments must provide green finance. Last but not least, encouraging research and development of green technologies and educating the public about the use of GE sources are crucial for enhancing environmental quality.
5. In order to advance environmental sustainability, countries must support green energy sources financially and legally. Similarly, increasing international collaboration for the transmission of green technologies and knowledge can speed up the use of green energy.

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