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RESEARCH ARTICLE

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Impacts of industrialization, renewable energy and urbanization on the global ecological footprint: A quantile regression approach

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Abstract

Debates on how growth and urbanization affect the environment have been intense, but they lack the global perspective. Therefore, this research examined those relationships, and to a greater extent other forms of global environmental degradation, such as foreign direct investment (FDI). It also explored the relationships between industrialization and technologies. The results, using Westerlund cointegration and quantile regressions over the period 1995–2017, show cointegration and regional heterogeneities in the environmental transmissions of economic development, industrialization, renewable energy, urbanization and FDI. The results show that economic development generates more environmental degradation in all quantiles at a global level, whereas urbanization and renewable energy reduce environmental degradation in all quantiles, with the highest effect being in the upper quantiles. On the other hand, industrialization affects the lower quantiles negatively and significantly but affects the upper quantiles positively. Finally, the empirical analysis supports the paradise haven or pollution halo hypothesis (PHH) for the 40th, 50th, 60th and 80th quantiles. This suggests that FDI inflows have a detrimental effect on the host country for these quantiles. Therefore, among the objectives of the policies are to give priority to more sustainable economic growth processes, which contribute to reducing environmental degradation, and furthermore to reinforce strict environmental laws on investment inflows and to build sustainable urbanization and industrialization processes for countries.

KEYWORDS
ecological footprint, environmental impact, environmental sustainability, industrialization, pollution halo hypothesis, quantile regression, renewable energy

1 | INTRODUCTION

The risks, many of them negative, of climate change are increasing so quickly that they could soon exceed the adaptive capacity of nature and humankind if the impact on the environment is not reduced rapidly, according to a major new scientific report by Pörtner et al. (2022) and presented by the United Nations. In this report, it is stated that 'adverse impacts are much more widespread and much more negative than expected'. This is observed in various parts of the world through heat waves, rising sea levels, drought and wildfires and recent cases of important floods in some countries of the European continent and the United States, causing damage to the global ecosystem. All these phenomena serious problems have raised global. With the objective to mitigate the impacts of climate change, coalitions between countries were created (Opoku & Aluko, 2021) for the implementation of global mechanisms to deal with climate change.

In this context (environmental degradation vs. the effects of climate change), there are many empirical studies carried out by researchers under the umbrella of environmental economics, in which the effects of different variables on environmental degradation include economic growth, urbanization and foreign direct investment (FDI), among others (Ahmed et al., 2021; Ali et al., 2020; Chu & Tran, 2022; Gyamfi et al., 2021; Nathaniel et al., 2020; Nathaniel & Khan, 2020). Similarly, empirical studies have also paid considerable attention to how the use of renewable energy affects the environment (see Adebayo et al., 2022; Aziz et al., 2021; Nathaniel et al., 2020). Most of them argue that the use of renewable energy is favourable for the environment. However, another large part of this literature studies how industrialization affects the environment directly (Fakher, 2019; Nwani et al., 2022; Salman et al., 2022b). Thus, the role of these two factors in the environment continues to be the subject of debate, as they are considered separately. In addition, there are few empirical arguments on this debate that focus their analyses on specific regions and not on a global sample.

This paper aims to fill this gap in the literature and provide a comprehensive analysis of the effect of these important factors on environmental degradation in a global scenario. Therefore, a sample of 106 countries was considered for the period 1995–2017. The methodology used in this econometric panel data study involves the use of quantile regression models in order to consider the heterogeneous effects of the independent variables on the ecological footprint (EF). The results show that factors such as economic growth, industrialization and FDI have a positive effect on environmental degradation, especially in the quantiles where developing economies are concentrated. This allows us to validate the pollution haven or halo hypothesis (PHH) on the quantiles where FDI was positive and significant. On the other hand, factors such as urbanization and the use of renewable energy help to reduce environmental degradation.

This paper is structured as follows. After introducing the subject under study and the objective of this research, in Section 2, the literature is reviewed, focusing on the impact factors of environmental degradation. The data and methodological estimation strategies are presented in Section 3. Section 4 reports and discusses the empirical results of the study. Finally, the conclusions, implications and limitations of the study are presented in Section 5.

2 | LITERATURE

Recent studies investigating the effect of economic growth, energy consumption and even urbanization on environmental degradation are up to date. However, the results of these studies always show large discrepancies due to variations in the range of data, methodologies adopted, proxy variables and the peculiarities of the countries or regions. The work of Usman et al. (2021) is along these lines. They investigate the effects of growth and renewable energy on the EF in 15 economies with the highest pollution levels by using an augmented mean group (AMG) estimation approach. They found that, on the one hand, growth based on industrial activities increases the EF considerably, while the use of renewable energy decreases this impact on the environment. In addition, Ahmad et al. (2020) provide evidence for 20 emerging economies, where growth increased the EF and innovations such as renewable energies led to a reduction in environmental degradation. Among the studies that show similar results, using alternative techniques to quantile regressions, we find Ahmed et al. (2020), Alola et al. (2019) and Usman et al. (2020).

On the other hand, using the quantile regression approach, the work of Awosusi et al. (2022) in BRICS (the acronym denoting the association of five large emerging economies: Brazil, Russia, India, China and South Africa) proposes that economic development affects environmental degradation heterogeneously, with the impact being higher in the lower quantiles and lower in the upper quantiles. Chu and Tran (2022) also show the same result for the economies that make up the Organization for Economic Cooperation and Development (OECD), validating the statement that the average effect differs and lacks validity when observing the heterogeneous effects on the EF. On the other hand, Aziz et al. (2021) claim that renewable energy reduces environmental degradation in the lower quantiles. However, the results are contradictory in the upper quantiles and imply that the total energy mix in countries is highly dependent on fossil fuels. These results were similar to those of Anwar et al. (2021) and Sharif et al. (2021) for the Association of Southeast Asian Nations (ASEAN) and the 10 economies with the largest EF, respectively.

By using fully modified OLS (FMOLS) and dynamic OLS (DOLS) estimators, Ulucak and Khan (2020) found that renewable energy and urbanization promote environmental quality in BRICS by reducing the EF. In addition, there must be a profound change in the quality of energy consumption to achieve Sustainable Development Goals (SDGs). In contrast, Ahmed et al. (2020) suggest that urbanization positively affects the EF in the G7 (Germany, Canada, the United States, France, Italy, Japan and the United Kingdom). Meanwhile, investment generates a favourable effect on the EF, linked to the absorption of cleaner production processes. Likewise, Nathaniel and Khan (2020) for the Middle East and North Africa (MENA) region suggest that urbanization contributes to environmental degradation. These same authors reveal that renewable energies do not contribute significantly to environmental quality. This is linked to an increase in the EF and a decrease in biocapacity due to the high rate of urbanization, high dependence on traditional innovations and the extensive use of fossil fuel resources (Salman et al., 2022a).

On the other hand, considering the effect coming from the industry level of an economy, we have the work of Liu et al. (2021), who in their analysis for 30 Chinese provinces found that it has a positive impact on environmental degradation in all quantiles. According to Raza and Hasan (2022), it is linked to the technological development of the industrial sector, which cannot reduce environmental degradation significantly due to energy quality problems. Nwani et al. (2022) also find the same impact in African economies, being more intense within countries with more extractive industries. This is linked to the capacity of the industry to improve its production processes and the fact that industries improve productivity through the flow of production factors within the industries themselves (Salman et al., 2022b).

In relation to the PHH, enunciated by Copeland and Taylor (1994), this refers to the fact that companies from rich countries with strict regulations moved to those countries, generally developing, in which their environmental regulations are comparatively weaker. In this way, developing countries will become pollution havens for the dirty industries of advanced countries with very strict regulations on environmental issues. In the work of Chowdhury et al. (2021), in a sample of 92 economies, it is observed that FDI has a positive relationship with the EF in each of the quantiles, except one, demonstrating the consistency of the PHH. Likewise, Gyamfi et al. (2021), in their study for sub-Saharan African countries, validate the PHH for a sample of oil and non-oil countries, suggesting that FDI inflows have a detrimental effect on the host country. Other empirical results show that conventional energy from fossil fuels and urban population deteriorate environmental quality in the regions examined. Other studies that reveal the link that enables environmental degradation through FDI are presented by An et al. (2021), Arogundade et al. (2022), Solarin et al. (2021) and Xu et al. (2022).

On the other hand, heterogeneous effects are considered in ASEAN-5 (Association of Southeast Asian Nations; Indonesia, Malaysia, Philippines, Singapore and Thailand) by Zhu et al. (2016), who claim that FDI, through the use of quantile regressions, impacts on environmental degradation negatively, except in the fifth quantile, and becomes significant in the upper quantiles. Likewise, both economic growth and population size have a negative effect on countries with high environmental degradation levels. The results are similar to Zafar et al. (2019) in the United States and Murshed et al. (2022) in Bangladesh. In fact, Chaouachi and Balsalobre-Lorente (2022) state that FDI contributes to reducing the negative impact of fossil sources on Algeria's energy mix by transitioning to a cleaner energy model through the use of renewable energy. Similarly, Gyamfi et al. (2022) argues that foreign investment focused on increasing the consumption of renewable energy improves the quality of the environment for the G7 countries (China, India, Brazil, Russia, Mexico, Indonesia and Turkey).

3 | METHODOLOGY

3.1 | Empirical model

Following the research carried out by Opoku and Aluko (2021), this research follows the framework of the Stochastic Impacts by Regressions on Population, Affluence and Technology-STIRPAT model developed by Dietz and Rosa (1997) 'that environmental degradation emanates from population, affluence and technological changes' (p. 175). This model was created to analyse 'the influences of population, industrialization level, affluence, technology, urbanization level and Kyoto protocol ratification on the environment' (Bargaoui et al., 2014, p. 449). Also, it is taken into account the PHH. As already mentioned, Copeland and Taylor (1994) postulated that the environment in developing countries deteriorates more rapidly. This is caused by its less strict environmental legislation and a greater economic opening that encourages the entry of companies from developed countries (with stricter environmental legislation). Generally, companies produce pollution-intensive products. Taking into account the above, an empirical model is proposed in which environmental degradation (EF) is expressed as a function of economic development, industrialization, renewable energy, urbanization and FDI.

$$EF = f(GDP, IND, RENW, URB, FDI) \quad (1)$$

where *GDP*, *IND*, *RENW*, *URB* and *FDI* represent economic development (gross domestic product [GDP]), industrialization, renewable energy, urbanization and FDI. The previous model is transformed into a stochastic model, and the resulting model is

$$EF_{it} = \rho_i + \gamma_1 GDP_{it} + \gamma_2 IND_{it} + \gamma_3 RENW_{it} + \gamma_4 URB_{it} + \gamma_4 FDI_{it} + \varepsilon_{it} \quad (2)$$

where ρ is the intercept of the model, ε is the error term, *i* represents the country and *t* represents the years.

3.2 | Variables and data

In this investigation, following Chowdhury et al. (2021) and Opoku and Aluko (2021), it was considered to measure the degree of environmental degradation of economies 'the Ecological Footprint' although in the literature review, it was observed that most of the investigations have considered the CO_2 emissions as measure (Cheng et al., 2021; Salman et al., 2019; Wang et al., 2019). The reason of use this variable 'is that ecological footprint is a wide-ranging measure relative to CO_2 emissions' (Opoku & Aluko, 2021, p. 177). In this sense, CO_2 emissions are largely limited to anthropogenic gases emitted from the combustion of coal, oil and gas from power plants, automobiles and industrial facilities. However, the EF measures the impact that humanity has on the planet generated by the demand for natural resources and energy and by the waste produced, as well as by the polluting emissions of the human being.

Economic development is measured through real GDP per capita in a similar way to studies such as that of Chu and Tran (2022) for OECD member countries and Gyamfi et al. (2022) in G7: Canada, France, Germany, Italy, Japan, the United Kingdom and the United States. The increase or creation of wealth is accelerated by an increase in economic activity that, being associated with the energy demand of a country, is also increased, therefore causing a great impact and environmental deterioration on many occasions. Ahmed et al. (2021) argue that regardless of whether a country is high, middle or low income, its development in terms of wealth is responsible for environmental degradation.

Another of the variables considered in the proposed model is industrialization (IND). Increasing industrialization brings about environmental concerns. Thus, industrialization has often been used as a metrics of impact on environmental degradation (see Opoku & Aluko, 2021). Following Rehman et al. (2021), we use 'Industrial Value Added' as a percentage of GDP to measure industrialization. A high-impact manufacturing sector induces the industrialization process, with the aim of improving the productivity levels of the population (Hassan et al., 2021).

The third variable of the model is 'Renewable energy' (RENW). The role of renewable energy consumption has been considered in recent studies, since it plays a prominent role in environmental degradation and environmental degradation also influences renewable energy consumption. According to Adebayo et al. (2022), the demand for renewable energy use has increased over the last decades and continues to increase day by day. This increase in energy demand may be due to population growth, lifestyle and improved competitiveness, among other reasons (Aziz et al., 2021).

Urbanization is the fourth variable in the model. Environmental degradation is likely to be greater in developing countries, which in turn have high rates of population growth and migration to cities (Nathaniel et al., 2020; Nathaniel & Khan, 2020). As in the case of other studies, urban population is considered to measure the effect of these processes within a country.

Finally, the last variable is 'Foreign Direct Investment' (FDI). The external influence usually reflects the degree of participation or influence a given economy has on the global market. FDI inflows are used to represent this external influence. Higher FDI inflows are always linked to fewer restrictions, which is why high-polluting enterprises are motivated to be relocated in countries with ambiguous or non-existent environmental regulations in host countries (Ali et al., 2020). This could lead to further environmental degradation. (See summary in Table 1.)

Regarding the sample, a balanced dataset is used for 107 countries worldwide from 1995 to 2017 (see Table A.1). The sample, both in terms of the number of countries and the selected period, is limited by the availability of information for each of the variables that make up the model. The variables are obtained from the World Development Indicators (WDI) database of the World Bank (2022). The EF is taken from the Global Footprint Network (GFN) (2019) database. Table 2 shows the descriptive statistics of the variables, and Table 3

TABLE 1 Summary of the data

Variable	Definition	Unit	Source	Obs.	Mean	Std. dev.	Min	Max
EF	Ecological footprint per capita	gha	GFN	2968	0.876	0.756	−1.168	2.877
GDP	Gross domestic product	Constant US$	WDI	2968	8.318	1.518	5.318	11.566
IND	Industrial value added	Percent	WDI	2968	3.237	0.349	1.516	4.286
RENW	Renewable energy	Percent	WDI	2968	2.959	1.611	−6.339	4.588
URB	Urbanization	Person	WDI	2968	15.721	1.594	11.373	20.511
FDI	Foreign direct investment	%	WDI	2968	3.581	5.957	−57.605	86.589

TABLE 2 Correlation matrix

	lnEF	lnGDP	lnIND	lnRENW	lnURB	FDI
lnEF	1.000					
t-stat	-					
lnGDP	0.870***	1.000				
t-stat	94.419	-				
lnIND	0.185***	0.233***	1.000			
t-stat	10.245	13.028	-			
lnRENW	−0.334***	−0.301***	−0.074***	1.000		
t-stat	−19.337	−17.185	−4.048	-		
lnURB	0.153***	0.305***	0.288***	−0.065***	1.000	
t-stat	8.451	17.454	16.392	−3.578	-	
FDI	0.202***	0.198***	0.020	−0.087***	−0.080***	1.000
t-stat	11.238	11.005	1.102	−4.804	−4.348	

***The parameter is statistically significant with a significance level of 1%.

TABLE 3 Panel unit root tests results

Variable	CADF		Bretung		CIPS	
	At level	At 1st difference	At level	At 1st difference	At level	At 1st difference
lnEF	−1.733*	−12.180***	1.088	−9.673***	−2.407***	−5.182***
lnGDP	−3.251***	−7.565***	6.773	−5.725***	−2.344***	−4.183***
lnIND	2.483	−8.605***	3.164	−10.006***	−2.024*	−5.308***
lnRENW	3.894	−11.017***	6.795	−8.677***	−2.478***	−5.261***
lnURB	−4.826***	−4.785***	2.023	−6.821***	−2.759***	−2.563***
FDI	−5.769***	−14.785***	−6.268***	−10.369***	−3.467***	−5.621***

*Significant level at 10%.
***Significant level at 1%.

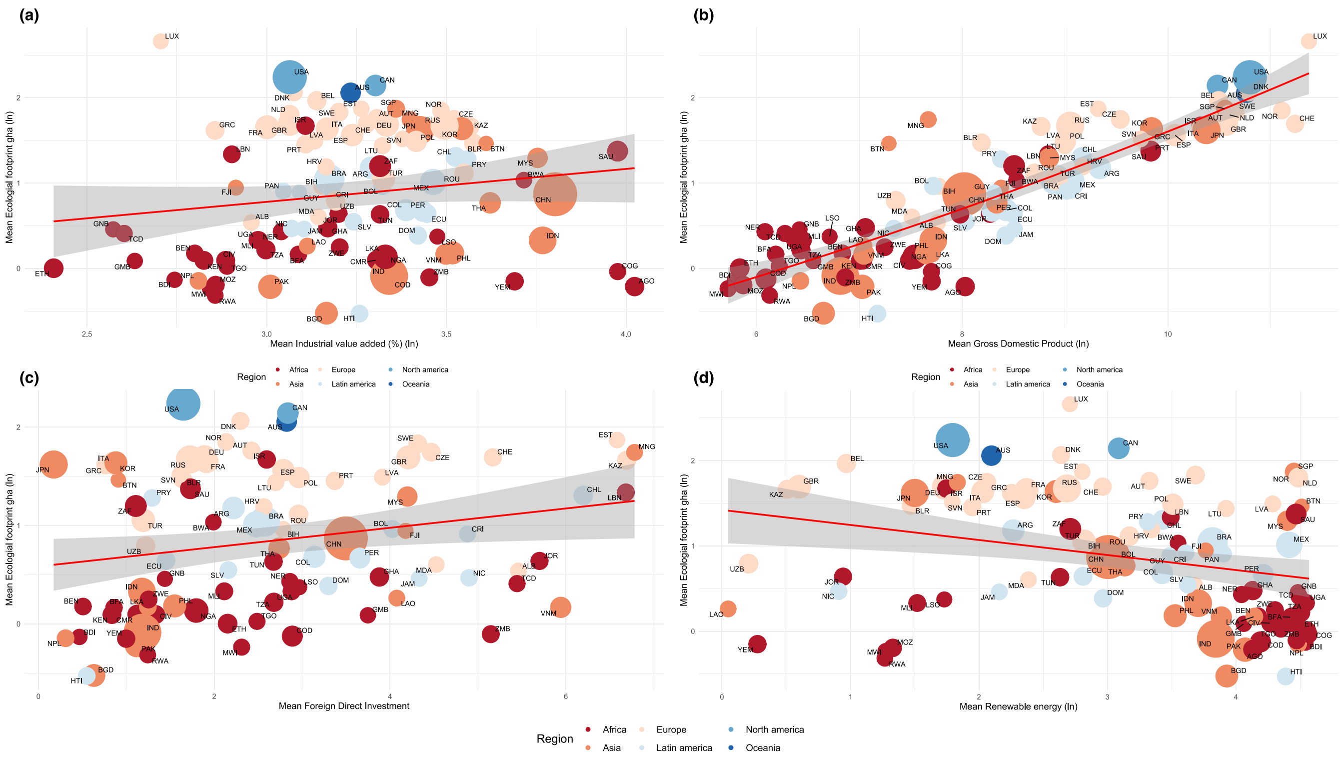

FIGURE 1 Ecological footprint, industry, GDP per capita and renewable energy. *Notes*: The arithmetic average (1990–2017) of variables. The size of the observation is according to the level of urbanization.

the correlations between them. For subsequent estimates, the natural logarithms of all the variables were considered in order to measure elasticities with respect to economic growth. With the exception of the FDI, which presents negative values in certain years, making the application of logarithms impossible.

In Table 2, it can observe that both industrialization (IND) and urban population (URB) present a positive correlation with environmental degradation as measured by the EF per capita, while renewable energy (RENW) shows a negative correlation. Similarly, economic development (GDP) shows a statistically positive and significant correlation coefficient, with a high correlation coefficient of 0.870. This suggests that EF and GDP are strongly correlated. In addition, external inflows measured by FDI have a relatively low correlation coefficient (less than 0.50). On the other hand, renewable energy (RENW) is the only indicator that shows a negative correlation with environmental degradation. Finally, it is observed that there are no high correlations (higher than 0.50) between the explanatory variables (independent), which provides a tendency for the empirical model not to be limited by the problem of multicollinearity.

4 | RESULTS AND DISCUSSION

In Figure 1, the relationships between the EF and economic growth (a), industry (b), renewable energy (c) and FDI (d) can be seen using the averages for each economy during the study period. This shows similar adjustments to those presented in Table 2, in which industrialization shows a positive adjustment with environmental degradation. Likewise, it is observed that in Panel b, economic growth adjusts positively with environmental degradation. In addition, African economies that have lower growth rates, at the same time, concentrate lower levels of environmental degradation. Similarly, the higher the external influence, the higher the levels of FDI, and the higher the level of degradation. Finally, renewable energies are adjusted negatively.

4.1 | Unit root test

In the panel model, stationarity analysis of the panel data must be performed before performing the regression (Wang et al., 2015). The use of non-stationary data leads to a spurious regression (regression that provides misleading statistical tests of a linear relationship between non-stationary independent variables), and the regression result is unreliable. In this research, three-panel unit root tests have been used to assess the steady state of the variables. Breitung's non-parametric unit root tests (Breitung, 2001) and Pesaran's CADF panel unit root test (Pesaran, 2004) are used, which serve as a contrast to the results of the CIPS test (cross-sectional Im Pesaran y Shin) (Pesaran, 2004). Table 3 shows the results of three-panel unit root tests (CADF, Bretung and CIPS). Here, it can be seen that, according to the results, all the variables reject the null hypothesis of non-stationarity of the data at 1%, in the first difference, that is, they are first order. Therefore, the relationship between the EF and GDP, IND, RENW, URB and FDI can be determined by the cointegration test.

4.2 | Panel cointegration test

Next, the panel cointegration test allows us to examine the long-run equilibrium between the variables. According to the cointegration theory for the treatment of time series, as long as there is cointegration between the dependent and independent variables, these variables can be used to build a model. Therefore, in order to avoid spurious regression and check whether the variables considered in the model are cointegrated (they evolve together in the long term), a specific panel data cointegration test is used (taking into account the time dimension and the transverse). The Westerlund (2007) test was used to examine the correlation between EF and GDP, IND, RENW, URB and FDI. Table 4 shows the results of the four tests defined by Westerlund (2007) that are used to verify the null hypothesis of no cointegration in a data panel (Gt, Ga, Pt, Pa). The results show the steady state of all variables in first-order difference. It is observed that three (Gt, Pt, Pa) of the four statistics reject the null hypothesis of no cointegration (*P*-value < 0.05), except for Ga. Therefore, the panel variables are cointegrated, or what is the same, there is a long-term equilibrium relationship between EF and GDP, IND, RENW, URB and FDI, which can be used to estimate the model. Based on the results obtained, it can be stated that the basic assumptions to estimate the quantile regression are fulfilled.

4.3 | Normal distribution test

Continuing with the analysis, it is verified whether the variables (EF, GDP, IND, RENW, URB and FDI) have a normal distribution or not in order to carry out the regression analysis below. When the sample data are not normally distributed, the results of the quantile regression estimation (minimizes a sum of weighted absolute errors with skewed weights) are more robust compared to the ordinary least squares (OLS) estimation (minimize the sum of squared residuals). Two methods have been used to study the normal distribution of the data: graphical method (Figure 2) and numerical tests (Table 5). The skewness coefficients of lnEF, lnGDP, lnIND, lnRENW, lnURB and lnFDI are significantly different from zero, and the kurtosis coefficients are not equal to 3 for any of the variables, indicating that these variables are not normally distributed (Table 5). Likewise, the probability values of the Shapiro–Wilk and Shapiro–Francia tests are less than 1%, which reaffirms that the variables are not normally distributed.

Continuing with the tests, to verify the distribution of a random variable, the theoretical quantile plot (Q–Q plots) was obtained (Figure 2).

The Q–Q plot can graphically show whether the data follow a normal distribution. The plot compares the quantiles of the observed distribution with the theoretical quantiles of a normal distribution with the same mean and standard deviation as the data. Therefore, the closer the data are to a normal, the more aligned the points are around the line. In Figure 2, it can be seen that in the Q–Q graphs, the data of the variables deviate from the straight line, indicating that the distribution is not normal.

TABLE 4 Westerlund (2007) ECM panel cointegration test

	Constant			Constant and trend		
Statistic	Value	Z-value	*P*-value	Value	Z-value	*P*-value
Gt	−3.948***	−16.280	0.000	−3.496***	−7.206	0.000
Ga	−8.376	6.183	1.000	−5.709	13.946	1.000
Pt	−52.806***	−28.232	0.000	−51.864***	−24.704	0.000
Pa	−17.704***	−11.459	0.000	−15.091*	−1.445	0.074

*Significant level at 10%.
***Significant level at 1%.

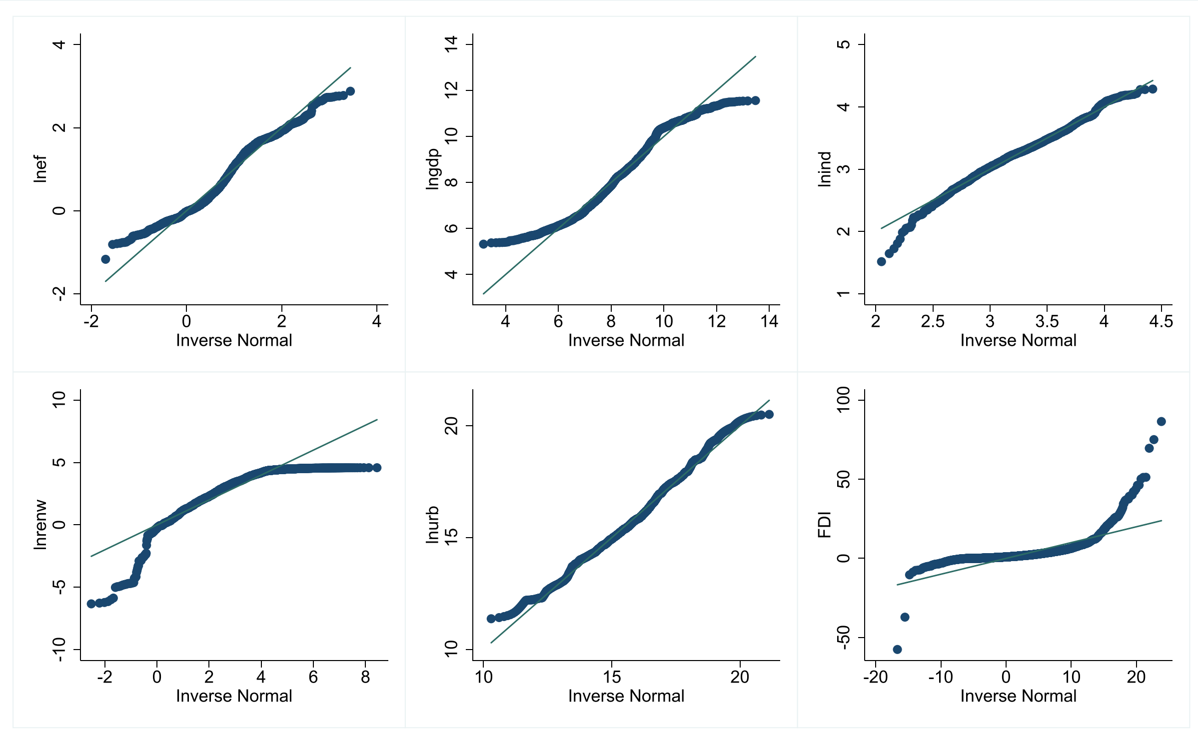

FIGURE 2 Normality graph of variables

TABLE 5 Tests of normal distribution

			Shapiro–Wilk test		Shapiro–Francia test		
Variable	Skewness	Kurtosis	stat	Sig.	stat	Sig.	Obs
lnEF	0.059	1.955	0.968	0.000	0.968	0.000	2698
lnGDP	0.148	2.026	0.970	0.000	0.971	0.000	2698
lnIND	−0.266	3.932	0.990	0.000	0.989	0.000	2698
lnRENW	−1.889	8.574	0.832	0.000	0.832	0.000	2698
lnURB	0.247	2.942	0.994	0.000	0.993	0.000	2698
FDI	4.186	44.759	0.587	0.000	0.585	0.000	2698

Taking into account the results of all the tests carried out, it can be affirmed that the study variables do not present a normal distribution.

4.4 | Panel quantile regression results

Since the normality tests showed that the model variables are not normally distributed, it is more appropriate to use panel quantile regression to estimate the model since this regression method does not make any assumptions about the distribution of the target variable. Its application allows obtaining the regression coefficients that estimate the effect that each predictor has on a specific quantile of the response variable. The quantile of order τ ($0 < \tau < 1$) of a distribution is the value of the variable X that marks a cut-off such that a proportion τ of values in the population is less than or equal to said value. However, due to fluctuations in the data, it is impossible to estimate each of the quantile values effectively. The quantile values alternating 10 units are used as proxy values for analysis.

The quantile results show that economic growth at all levels has a statistically significant positive effect at 0.1% on the EF and the estimated parameters follow a decreasing pattern. These results do not vary in symbol, that is, the positive effect is maintained and increases the EF at all levels. The results for this variable are consistent with Ahmad et al. (2020), whose results are similar for 20 emerging economies. Similarly, Awosusi et al. (2022) show similar evidence for BRICS, where the heterogeneous impacts of economic development gradually affect the EF. The studies by Ahmed et al. (2020), Alola et al. (2019) and Usman et al. (2020) also confirm the research results.

The results of industrialization in the initial quantiles show a negative and significant effect on the EF in the first quantiles. However, the effect increases positively and affects the upper quantiles, starting

TABLE 6 Quantile regression results

		Quantile regression			
	OLS	10th	20th	30th	40th
lngdp	0.442*** (0.005)	0.486*** (0.008)	0.474*** (0.008)	0.457*** (0.004)	0.451*** (0.003)
lnind	−0.0242 (0.019)	−0.339*** (0.042)	−0.213*** (0.042)	−0.0617* (0.031)	−0.0227 (0.023)
lnrenw	−0.0409*** (0.004)	−0.0216** (0.007)	−0.0339*** (0.005)	−0.0342*** (0.004)	−0.0342*** (0.004)
lnurb	−0.0554*** (0.004)	−0.0260** (0.008)	−0.0330*** (0.009)	−0.0387*** (0.005)	−0.0438*** (0.003)
FDI	0.00159 (0.001)	0.00315 (0.002)	0.00109 (0.001)	0.00136 (0.001)	0.00300* (0.001)
Constant	−1.745*** (0.082)	−2.049*** (0.194)	−2.031*** (0.139)	−2.180*** (0.094)	−2.110*** (0.067)
Observations	2968	2968	2968	2968	2968

Note: Values in parentheses are standard errors.
*Significant level at 10%.
**Significant level at 5%.
***Significant level at 1%.

TABLE 6 (Continued)

	Quantile regression				
	50th	60th	70th	80th	90th
lngdp	0.443*** (0.004)	0.437*** (0.008)	0.426*** (0.007)	0.400*** (0.008)	0.399*** (0.007)
lnind	0.00394 (0.029)	0.0549 (0.041)	0.137*** (0.036)	0.149*** (0.034)	0.163*** (0.044)
lnrenw	−0.0321*** (0.005)	−0.0336*** (0.007)	−0.0326*** (0.006)	−0.0429*** (0.009)	−0.0529*** (0.012)
lnurb	−0.0473*** (0.004)	−0.0590*** (0.007)	−0.0759*** (0.010)	−0.0767*** (0.009)	−0.0772*** (0.008)
FDI	0.00373*** (0.009)	0.00354* (0.002)	0.00281 (0.002)	0.00287* (0.009)	0.000839 (0.001)
Constant	−2.025*** (0.081)	−1.870*** (0.139)	−1.664*** (0.153)	−1.321*** (0.124)	−1.178*** (0.141)
Observations	2968	2968	2968	2968	2968

Note: Values in parentheses are standard errors.
*Significant level at 10%.
**Significant level at 5%.
***Significant level at 1%.

precisely from the 70th quantile. In addition, we can observe that the estimated parameters increase in size as the quantile is higher, following an increasing pattern. This is compatible with Raza and Hasan (2022), who claim that this second effect is associated with the high dependence of production processes on fossil energy sources, in addition to the high demand for factors, especially in the early stages of the growth of countries (Nwani et al., 2022; Salman et al., 2022b). On the other hand, the initial effect could be linked to the improvement in productivity, that is, moving from an economy based on extractive activities that predominantly impact on the environment towards less polluting activities such as manufacturing (Fakher, 2019).

Renewable energy sources show a negative and significant effect on the EF at all quantile levels (Table 6). These effects show a decreasing pattern with a slight variation in the 60th quantile. The result validates the potential of these renewable sources with the aim of reducing the growing impact on the EF. Ulucak and Khan (2020) and Ahmad et al. (2020) confirm that a profound change in the quality of energy consumption makes innovations such as renewable energy sources essential to reduce the EF of regions, with the aim of achieving SDGs. In contrast, Nathaniel and Khan (2020) claim that such an effect does not exist for the MENA region. Furthermore, the high dependence on fossil fuel resources overshadows the effect of renewable energy on the EF (Salman et al., 2022a).

Further analyses show that urbanization has a negative effect on the EF, which is significant at 0.1% in all quantiles. Likewise, it is observed that the parameters follow a decreasing pattern, which is the same pattern that is observed in Figure 3. This result shows that the growth of cities and the transition of the population from the rural to the urban sector favours the reduction of environmental degradation. This is related to the shift from the use of traditional energy to cleaner energy. Ahmad et al. (2021) show the opposite result to that found in this study, stating that urbanization increases the EF of the G7 economies. Likewise, Nathaniel (2021) and Salman et al. (2022a) propose that this positive impact is linked to an increase in the EF and a decrease in biocapacity due to the high urbanization rate in developing economies.

Finally, FDI has a positive but not a significant effect on all levels, except for the 40th, 50th, 60th and 80th quantiles. Similarly, it can be observed that the parameters show a decreasing effect on environmental degradation. This result confirms that in economies with high investment levels, the PHH is fulfilled, especially in economies that are in the process of development. This implies that the economies that are in the 40th, 50th, 60th and 80th quantiles are hosts and economies that invest in them transfer their polluting processes to these economies. This result is supported by Chowdhury et al. (2021) in a similar panel of countries. Similarly, Gyamfi et al. (2021) suggest that the production processes implemented by foreign companies are based on fossil energy sources in host economies. Likewise, An et al. (2021), Arogundade et al. (2022), Solarin et al. (2021) and Xu et al. (2022) confirm these results in different regions. On the contrary, Chaouachi and Balsalobre-Lorente (2022) claim that the impact is negative and is conditioned to energy transitions of the host economies to cleaner sources such as renewable sources.

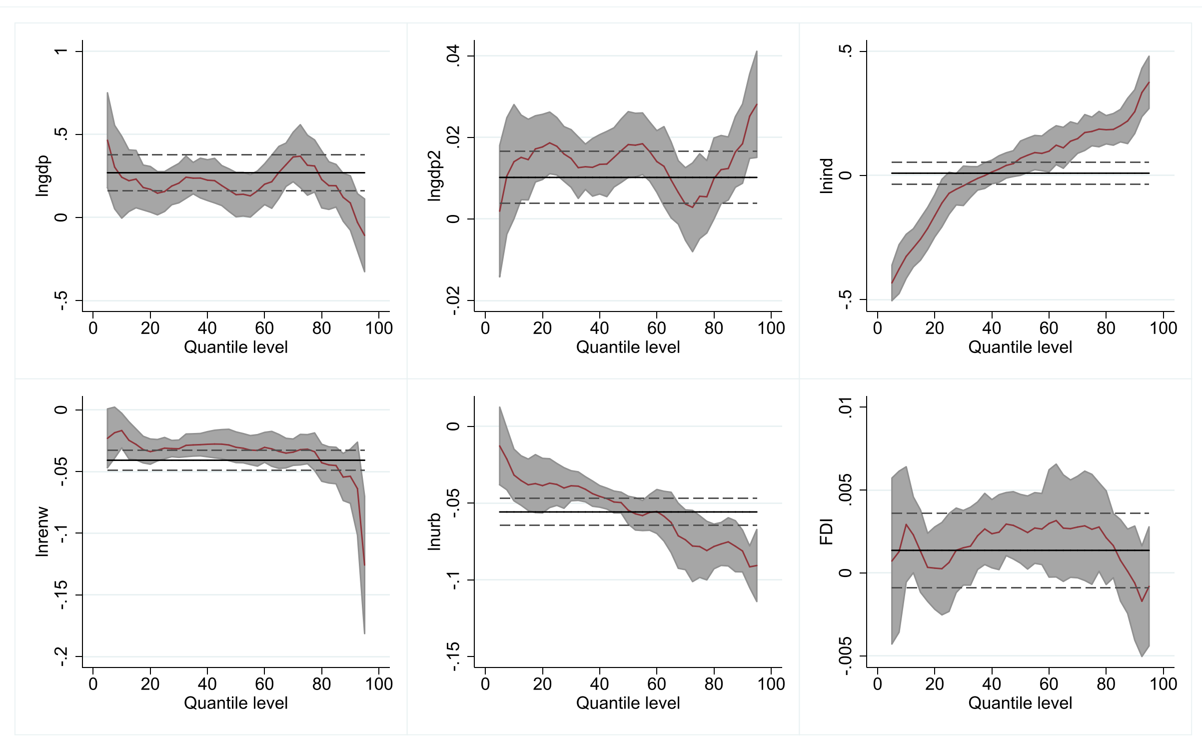

FIGURE 3 Quantile distribution of different independent variables on ecological footprint

TABLE 7 Country distribution in terms of ecological footprint

Quantile	Country
10th	Angola, Bangladesh, Burundi, DR Congo, Gambia, Haiti, Malawi, Mozambique, Pakistan, Rwanda and Yemen
20th	Burkina Faso, Congo, Ethiopia, Kenya, Nepal, Nigeria, Sierra Leone, Togo, Uganda, Zambia and Zimbabwe
30th	Benin, Cameroon, Cote d'Ivoire, Guinea-Bissau, India, Lesotho, Mali, Philippines, Sri Lanka and Tanzania
40th	Chad, Colombia, Dominican Republic, Ecuador, Indonesia, Jamaica, Jordan, Moldova, Nicaragua and Niger
50th	Albania, Botswana, Costa Rica, El Salvador, Fiji, Ghana, Laos, Mexico, Panama, Peru, Thailand, Tunisia, Uzbekistan and Viet Nam
60th	Argentina, Bolivia, Bosnia and Herzegovina, Brazil, China, Croatia, Guyana, Lebanon Paraguay, Romania, South Africa and Turkey
70th	Belarus, Bhutan, Chile, France, Germany, Greece, Italy, Japan, Malaysia, Poland, Portugal, Slovakia, Slovenia, Spain, Switzerland and United Kingdom
80th	Czech Republic, Israel, Lithuania, Netherlands, Norway, Russia, Saudi Arabia, Singapore and Turkmenistan
90th	Australia, Austria, Belgium, Canada, Denmark, Estonia, Kazakhstan, Latvia, Luxembourg, Mongolia, South Korea, Sweden and United States

In this research, emerging countries are classified into six groups (Table 7), taking into account the EF. Based on the EF level, we divide the 107 economies into nine levels.

In addition, in this study, to estimate the fixed effects results of the panel data model, OLS regression was used (see Figure 3).

5 | CONCLUSIONS AND RECOMMENDATIONS

This study investigated the impact of industrialization, renewable energy and FDI on the EF for 106 economies worldwide, from 1995 to 2017. The panel quantile regression model was presented as a more suitable alternative analysis to measure the heterogeneous impact of the independent variables on the dependent one. However, prior to obtaining the empirical results, preliminary tests were applied, which showed that multicollinearity between the variables is not a problem for this analysis. Furthermore, the variables included in the model are integrated of order I (1). This allowed us to observe the existence of a long-term equilibrium relationship between the EF and other variables and the presence of a non-normal distribution in the variables. In fact, these characteristics demonstrate that the use of the panel quantile regression model approach is the most appropriate and well adapted to this research.

The results of the panel quantile regression model revealed that economic development implies environmental degradation in all quantiles and decreases with increasing development. Meanwhile, the use of renewable energy, urbanization and industrialization (in the first 10th, 20th and 30th quantiles) has a negative and significant effect on the EF of the selected sample.

However, FDI specifically affected the 40th, 50th, 60th and 80th quantiles positively, validating the PHH. This implies that these developing economies absorb the deterioration of economies through FDI, effectively putting the jurisdictions with less strict environmental regulations in these host economies.

5.1 | Practical implications

The empirical results of this research will allow for the development of energy transition policies and environmental regulations that reduce the environmental problem. In particular, policymakers should change existing policies to encourage uptake of green energy technologies to replace fossil fuel consumption in industries. In addition, policymakers must develop strategies to reduce bureaucracy and promote institutions to encourage energy and environmental laws that limit the entry of polluting processes by foreign companies.

5.2 | Theoretical contribution

Furthermore, this research makes a significant contribution to the literature for several reasons. Firstly, it considers two factors that are taken individually in other studies: the use of renewable energy and industrialization. Secondly, the empirical results of this research have critical implications for governments and policymakers. This research is an opportunity for policymakers and governments to reconsider current policies that are not environmentally feasible. Finally, this work aims to go beyond a region-by-region analysis and give a more global view of the factors that have an effect on environmental degradation.

5.3 | Research limitations

The limitations linked to this article are related to the lack of information, due to the availability of data on the EF and renewable energy variables. This also limited the analysis period to 2017. That is why future studies could include alternative factors to the EF, such as nitrogen and sulfur emissions for a deeper analysis. In addition, according to the development of the new empiricalmethodology, advanced methodologies can be applied for empirical analysis linking to the heterogeneous effects presented by the data panels.

CONFLICTS OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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APPENDIX A

TABLE A.1 Sampled countries

Country name			
Albania	Czech Republic	Lebanon	Saudi Arabia
Angola	Denmark	Lesotho	Sierra Leone
Argentina	Dominican Republic	Lithuania	Singapore
Australia	Ecuador	Luxembourg	Slovakia
Austria	El Salvador	Malawi	Slovenia
Bangladesh	Estonia	Malaysia	South Africa
Belarus	Ethiopia	Mali	South Korea
Belgium	Fiji	Mexico	Spain
Benin	France	Moldova	Sri Lanka
Bhutan	Gambia	Mongolia	Sweden
Bolivia	Germany	Mozambique	Switzerland
Bosnia and Herzegovina	Ghana	Nepal	Tanzania
Botswana	Greece	Netherlands	Thailand
Brazil	Guinea-Bissau	Nicaragua	Togo
Burkina Faso	Guyana	Niger	Tunisia
Burundi	Haiti	Nigeria	Turkey
Cameroon	India	Norway	Turkmenistan
Canada	Indonesia	Pakistan	Uganda
Chad	Israel	Panama	United Kingdom
Chile	Italy	Paraguay	United States
China	Jamaica	Peru	Uzbekistan
Colombia	Japan	Philippines	Viet Nam
Congo	Jordan	Poland	Yemen
Congo DR	Kazakhstan	Portugal	Zambia
Costa Rica	Kenya	Romania	Zimbabwe
Cote d'Ivoire	Laos	Russia	
Croatia	Latvia	Rwanda	