FOREIGN DIRECT INVESTMENT AND CARBON EMISSIONS IN EUROPE: RETHINKING ENVIRONMENTAL SUSTAINABILITY THROUGH RENEWABLE ENERGY AND INTELLECTUAL CAPITAL

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Abstract. This paper examines the relationship between foreign direct investment (FDI) and environmental sustainability in 27 European Union countries and the United Kingdom, focusing on the role of human intellectual capital from 1998 to 2023. The study employed the Panel Autoregressive Distributed Lag (ARDL) approach to achieve its objectives. Results show that FDI inflow has a positive and significant impact carbon emissions, proving that environmental risks are related to uncontrolled foreign capital in carbon-intensive sectors. Interestingly, the adoption of renewable energy significantly contributes to reducing the carbon footprints. Nevertheless, intellectual capital, captured by upper secondary educational achievement, contrary to the "a priori" expectation, shows a positive association with carbon emissions, raising questions about the assumed environmental benefits of education. Short-run dynamics show no significant immediate effects from these variables. The study recommends rigorous climate-conscious FDI screening, reinforcing green growth policies, enhancing renewable energy adoption, and integrating sustainability literacy into educational curricula to align intellectual development with environmental goals.
Keywords: *green finance, technological innovation, knowledge-based economy, clean energy transition, sustainable development, panel data analysis*
JEL codes: *F21, Q43, Q56, I25*

Introduction

Investments are known to be among the key forces stimulating economic growth, promoting capital accumulation, technological innovation and employment creation across countries (Osabohien et al., 2022). However, the environmental risks associated with FDI remain controversial in the literature and policy dialogue, especially in the context of Europe's strong climate commitments. Europe, characterized by strong economic integration and stringent environmental strategies under frameworks like the European Green Deal, offers an exemplary case to examine the dynamics between foreign investment inflows and environmental sustainability.

Extant studies based on the association among FDI and environmental sustainability often report mixed outcome. While some extant studies in the literature present the significant role FDI play in enhancing technological transfers for the mitigation of environmental hazards, others highlight the Pollution Haven Hypothesis, recommending that FDI inflows has the potential to worsen carbon emissions, particularly, in countries with moderately relaxed environmental principles (Ozkan et al., 2023; Wang et al., 2023). Simultaneously, the transition of European countries to the adoption of renewable energy has occurred as a fundamental strategy for the actualization significant decline in carbon emissions, emphasizing the continent's decarbonization goals (Osabohien et al., 2025a Mukhtarov et al., 2023; Dong et al., 2021; Saidi and Omri, 2020).

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Furthermore, another critical but relatively novel and underexplored aspect of in the extant literature is the role of human intellectual capital in affecting environmental outcomes. Hypothetically, advanced educational levels and intellectual prowess should associate significantly with enhanced environmental consciousness and better implementation of innovative, sustainable practices. Nevertheless, findings from the empirical studies remain mixed, with some studies showing unanticipated association contingent on the nature and orientation of educational systems (Haq et al., 2024; Yao et al., 2020).

Existing literature on foreign direct investment (FDI) and environmental sustainability presents mixed results, highlighting a significant gap concerning the specific situations in which FDI affects carbon emissions in Europe. Prior literature, most times, focus narrowly on direct FDI-environment associations, overlooking moderating series like the adoption of renewable energy adoption and intellectual capital. Also, the assumption that higher educational attainment (intellectual capital) inherently promotes environmental sustainability remains inadequately examined empirically, particularly within the EU context.

This study addresses these gaps by empirically evaluating the impact of FDI inflows, renewable energy consumption, economic growth, and intellectual capital on carbon footprints across 27 European Union (EU) member states and the United Kingdom (UK) from 1998–2023. It extends existing knowledge by employing the robust Panel ARDL approach, providing a novel perception into both short-run frictions and long-run structural associations. Notably, it poses a challenge to the traditional expectations by unveiling that an upward shift in learning curve, regarded as educational achievement, relates significantly with more carbon emissions, suggesting the necessity for education systems to explicitly integrate sustainability. Consequently, this current study expressively expands the extant literature on sustainable economic policy by identifying significant areas for policy intervention, including climate-focused FDI screening, renewable energy policy acceleration and strategic reorientation of intellectual capital toward environmental consciousness.

Review of literature

The association existing among Foreign Direct Investment (FDI) and environmental sustainability has been subjected to extensive dialogue in policy and extant literature. Scholars posit two predominant, yet inconsistent, theories, the Pollution Haven Hypothesis (PHH) and the Pollution Halo Hypothesis (Birdsall et al., 1993; Copeland et al., 1994; Eskeland et al., 2003). The Pollution Haven Hypothesis suggests that multinational corporations relocate pollution-intensive industries to regions with lenient environmental regulations to minimize operational costs, thereby exacerbating environmental degradation (Ozkan et al., 2023; Wang et al., 2023). Conversely, the Pollution Halo Hypothesis argues that FDI brings advanced technology and higher environmental standards, improving environmental outcomes in host countries (Adeleye et al., 2021; Mohamed et al., 2024).

Empirical examinations into these frameworks resulted in mixed findings. Wang et al. (2023), for example, highlight a significant association amongst FDI and carbon emissions in lower-income countries, validating the Pollution Haven perspective. Likewise, Ozkan et al. (2023) posits a significant environmental risk correlated with uncontrolled FDI inflows in developing countries, especially, due to weak institutional

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frameworks. On the other hands, other researchers highlight the possibility of FDI to offer eco-friendly technologies and improve ecological standards via monitoring spill-overs and corporate social responsibility ingenuities. Adeleye et al. (2021) and Mohamed et al. (2024) discuss how FDIs in renewable energy and cleaner technologies significantly contribute to emission reductions in host nations, indicating partial validity of the Pollution Halo hypothesis.

Transitioning to renewable energy sources is extensively given attention as an essential element of global climate strategy. Plethora evidence aligns renewable energy's efficiency in expressively mitigating carbon footprints. Mukhtarov et al. (2023) and Dong et al. (2021) disclose strong opposite associations amid renewable energy consumption and carbon emissions across various economic backgrounds. Also, Saidi and Omri (2020) find renewable energy adoption as a key influence in carbon reduction among Organisation for Economic Co-operation and Development (OECD) countries, demonstrating renewables as a fundamental factor for actualizing sustainability goals.

Osabohien et al. (2025) examined the nexus between renewable energy, carbon footprints, natural resource depletion, and economic growth in 45 African countries, using GMM. Findings reveal greenhouse gas emissions boost growth, resource depletion harms it, and renewable energy moderates' outcomes, highlighting region-specific pathways for sustainable development.

Europe, under the determined European Green Deal, focuses to attaining Net Zero target by 2050, meaningfully capitalizing in renewable energy infrastructures such as solar, wind, and bioenergy. Existing literature constantly demonstrates renewable energy's transformative part in Europe's energy landscape, encouraging considerable emission decrease and promoting environmental sustainability (Imandojemu et al., 2025; Zheng et al., 2023). Furthermore, renewable energy adoption hastens technical invention and economic reform toward low-carbon industries, confirming its importance to Europe's decarbonization plan (Dong et al., 2021).

The role of human intellectual capital, especially, education and knowledge systems in environmental sustainability is an area of evolvement in economic-environmental research. Hypothetically, improved intellectual capital suppose enhance higher environmental consciousness, better efficiency, and speedy technological revolution. Romer's (1990) endogenous growth theory highlights human capital as crucial for innovation-led sustainable growth. Furthermore, Rogers' (2003) theory on diffusion of innovations implies that intellectual capital significantly accelerates the adoption and effective utilization of sustainable technologies.

However, empirical findings with respect to intellectual capital's environmental impact remains inconsistent. Yao et al. (2020) show that higher education levels associate with diminished carbon emissions as a result of sensitive environmental consciousness and innovation capabilities. On the other hand, Haq et al. (2024) find opposing impact of intellectual capital on carbon emissions, positing that there exist an inverse association in OECD countries, however, insignificantly associated emerging markets such as countries within the BRICS (Brazil, Russia, India, China, and South Africa) economic bloc. These mixed findings highpoint the multifaceted, context-dependent connection between educational attainment and environmental sustainability, suggesting that not all educational frameworks inherently support sustainability.

Grossman and Krueger (1995) initially proposed that environmental impacts intensify during initial economic growth phases but subsequently diminish beyond a specific income threshold, driven by technological advancement and stricter regulatory

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frameworks. Ozkan et al. (2023) reaffirm the Environmental Kuznet Curve (EKC) hypothesis, demonstrating reduced carbon emissions associated with higher income levels, largely due to increased investment in environmentally friendly technologies and stringent environmental regulations. Empirical validation of the EKC hypothesis remains mixed, especially within the European context. Adeleye et al. (2021) highlight cases where increased economic growth continues to correlate positively with environmental degradation, particularly when growth relies heavily on industrialization and fossil fuels. Conversely, evidence from Europe increasingly indicates a decoupling of economic growth from environmental impact, reflecting successful structural transitions toward greener, service-oriented economic models (Mohamed et al., 2024; Imandojemu et al., 2025).

Li et al. (2025a) investigated how optimized multi-energy systems can accelerate carbon neutrality, emphasizing the relevance of integrated planning in decarbonization efforts. Similarly, the study by Song et al. (2025) and Meng et al. (2023) examined the operational efficiency gains from integrating renewable generation, hydrogen systems, and carbon constraints into energy planning, reinforcing the potential of capital-intensive infrastructure to reduce emissions over the long term. In examining the integration of digital transformation into green systems as a critical driver of sustainability, Yan et al. (2025) analyzed the effect of digitalization and how it enhances green supply chain systems, enabling improved resource allocation, waste reduction, and emissions control. Similarly, Cai et al. (2025) adopt a holistic sustainability lens, finding that circular economy principles generate positive spillovers in environmental, economic, and social dimensions, thereby multiplying the returns on green investments. These findings are reinforced by Li et al. (2025b), who found that collaborative data-sharing markets can strengthen systemic efficiency, which is relevant to Europe's pursuit of interconnected clean energy and innovation ecosystems.

In terms of financing and innovation, Dong and Yu (2024) provide evidence that green bond issuance in the energy sector catalyzes green innovation, facilitating the shift away from fossil fuels. This aligns with the study of Wang and Luo's (2025) which evaluated the credit guarantee mechanisms for SMEs, which if targeted at clean tech could expand the renewable energy value chain. Niu et al. (2022) and Jin et al. (2023) added the technical perspective, showing how advanced thermodynamic systems and integrated energy scheduling optimize renewable penetration and improve system reliability, further validating the long-run environmental benefits of technological investments.

From a macroeconomic and capital flow perspective, Dong and Yu (2024) explore how external shocks influence cross-border capital flows, underscoring the volatility risks associated with financing large-scale sustainability transitions. This links directly to FDI in renewable energy, where stable policy and institutional quality can determine the pace of carbon emissions reduction. Yang et al. (2024) contribute methodological innovations for capturing heterogeneity in sustainability outcomes across regions, offering analytical tools for assessing the varied impacts of FDI on carbon mitigation. Also, intellectual capital plays a foundational role as the capacity to design, manage, and adapt clean energy systems is inherently tied to human expertise, collaborative networks, and innovation culture. Cai and Zhang (2025), though focusing on creative search algorithms, emphasized the productivity gains from coordinated and knowledge-driven development, a principle directly applicable to renewable energy research and development in Europe.

Irrespective of the plethora body of studies providing evidence of different components of FDI, renewable energy, intellectual capital and environmental

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sustainability independently, substantial draw back continue to exist with respect to their combined impact, especially, within the European context. First, current literature mainly examines direct associations amongst FDI and environmental outcomes, mostly ignoring interactive impact linking renewable energy and intellectual capital. Secondly, while renewable energy adoption is well-documented as important for the reduction of carbon emission, relatively sparse literature examine its moderating effect on the FDI-environment nexus comprehensively. Furthermore, investigation interrogating intellectual capital's nuanced environmental effects remains inadequate. The postulation that improved educational achievement automatically leads to sustainable environmental outcomes is inadequately supported empirically, especially in developed regions such as Europe, where high education levels coexist with complex consumption patterns and urbanization, to the author's best of knowledge.

This manuscript extends the frontiers of knowledge by addressing these drawbacks through a comprehensive empirical investigation. The study engaged advanced econometric procedures (Panel ARDL), it instantaneously assesses how renewable energy adoption and intellectual capital effect the connection amongst FDI inflows and carbon emissions across 27 European countries and the UK. This integrative method not only improves the existing dialogue but also offers significant insights into designing policies that harness FDI's potential for sustainable growth.

By identifying the unexpected positive association between intellectual capital and carbon emissions, this study highlights the need for targeted educational reforms that explicitly integrate sustainability education and climate awareness. Moreover, by confirming renewable energy's robust moderating effect, the study reaffirms and improves renewable energy's strategic importance within Europe's climate and energy policies. In summary, this literature review synthesizes the complexities surrounding FDI, renewable energy, intellectual capital, and environmental sustainability. It highlights significant theoretical debates, empirical divergences and policy implications, while positioning the current study as a timely and valuable contribution to sustainable economic policy discourse.

Materials and methods

Variable proxies, measurement and sources

In this analysis, carbon footprint in Europe is realized as a function of foreign direct investment. The study further controls for economic activities involving emitting energy sources, renewable energy adoption and intellectual capital that defines the potential of these economies to innovate and embrace green practices. The empirical model adopted here follows Joo and Shawl (2023) and Shaari et al. (2020). The functional form of the model is therefore stated in *Equation 1*.

$$CARBON_{it} = f(FDI_{it},\ Act_{it},\ ICA_{it},\ REN_{it}) \qquad \text{(Eq.1)}$$

To translate this abstract economic relationship into a testable empirical equation, with clearly isolated parameters, we specify the econometric as shown in *Equation 2*.

$$CARBON_{it} = \beta_0 + \beta_1 FDI_{it} + ACT_{it} + ICA_{it} + REN_{it} + \varepsilon_{it} \qquad \text{(Eq.2)}$$

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where: $CARBON_{it}$ means Carbon footprint of country i at time t. FDI_{it} represents FDI inflows in renewable energy of country i at time t. REN_{it} captures Renewable energy adoption of country i at time t. ICA_{it} is the EU intellectual capital in country i at time t. ACT_{it}represents economic activities measured as GDP % annual growth of country i at time t. ε_{it} is the error term.

This model is estimated using the Panel ARDL (Pooled Mean Group/Mean Group) procedure. The specific case here using the variables employed in the study is shown as:

$$\begin{aligned}\Delta \ln CARBON &= \phi_i(\ln CARBON_{i,t-1} - \beta_1 FDI_{i,t-1} - \beta_2 ACT_{i,t-1} - \beta_3 REN_{i,t-1} - \beta_4 ICA_{i,t-1}) \\ &+ \sum_{j=j}^{1}\alpha_1 \Delta FDI_{i,t-j} + \sum_{j=1}^{1}\alpha_2 \Delta ACT_{i,t-j} + \sum_{j=1}^{1}\alpha_3 \Delta REN_{i,t-j} + \sum_{j=1}^{1}\alpha_4 \Delta ICA_{i,t-j} + \varepsilon_{it}\end{aligned} \quad \text{(Eq.3)}$$

In the Panel ARDL model (*Eq. 3*), the variable definitions are as in *Equation 2*. However, ϕ_i relates to the error correction term; $\beta_0 - \beta_{41}$ are the long run parameters to be estimated from *Equation 3*; $\alpha_1 - \alpha_4$ are the short run coefficients; ε is the error term.

This study employs annual frequency data on 27-member countries of the European Union and the United Kingdom from 1998 to 2023. These data are sourced from reputable data repositories. Specifically, data on carbon foot print (CARBON) are obtained from Our World in Data while foreign direct investment (FDI), renewable energy adoption (REN), economic activity (ACT) and intellectual capital (ICA) have their data sources in World Development Indicators. For clarity of purpose, the variable acronyms, measurement of the proxies for these variables are presented in *Table 1*.

Table 1. *Variable types, acronyms, measurement of proxies and data sources*

Type	Variable	Symbol	Measurement	Source
Dependent	Carbon footprint	CARBON	Carbon emissions in gigagrams of carbon dioxide equivalent, associated with the consumption of goods and services within a country	Our World in Data
Explanatory	Foreign direct investment	FDI	Foreign direct investment, net inflows (% of GDP)	WDI
Control variables	Economic activity	ACT	GDP growth (annual %)	WDI
	Renewable energy adoption	REN	Renewable energy consumption (% of total final energy consumption)	WDI
	Intellectual capital	ICA	% share of all adults aged 25 that have attained upper secondary education	WDI

Source: Author's own work

D Pesaran cross sectional dependency (CD) test

Before estimating the PMG model, this study summarized the distributional futures of the series. Why this procedure may not be directly important in the case of panel ARDL models, it is generally useful in decisions relating to variable transformation (Pesaran, Shin and Smith, 1993). The descriptive statistics employed in this study are mean, the median, kurtosis and skewness as well as Jacque Bera Statistics. In order to eliminate the

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chance of highly correlated independent variables (Multicollinearity), the study performed a snap check using pairwise correlation among the variables.

The study conducted a series of diagnostic tests that serve as essential precursors to panel ARDL estimation to ensure the robustness of the empirical strategy and the validity of inference. For instance, the Pesaran (2004) Cross-sectional Dependence (CD) test, panel unit root tests, and the Hausman test were used. Taken together, the results of these tests form the practical premise on which the long-run and short-run dynamics of the model are interpreted. To avoid the risk of oversimplification, given the nature of panel data covering the 27 EU member states and the UK, from 1998–2023 it is statistically expedient to determine the independence across the panel members. This is particularly important because shared shocks are inherent influence on economic, environmental and energy variables of the character employed in this study. To assess whether residuals are contemporaneously correlated across countries, the Pesaran CD test was employed. The null hypothesis of the test posits cross-sectional independence, and rejection implies the presence of common unobserved factors or spillover effects across countries.

The Pesaran CD test statistic is based on the mean of the pairwise correlation coefficients of the residuals from individual units:

$$CD = \sqrt{\frac{2T}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}}$$

where: T captures the number of time periods; N represents the number of cross-sectional units (countries in this case); $\hat{\rho}_{ij}$ is the estimated pairwise correlation between residuals of cross-sectional units i and j

Panel unit root and Hausman tests

The stationarity properties of all variables were tested to prevent spurious regressions and misinterpretation of dynamic relationships examined. The Levin, Lin and Chu procedure was used and its sensitivity is tested using the Im, Pesaran and Shin. Both the Levin, Lin & Chu (LLC) and Im, Pesaran & Shin (IPS) tests were deployed to diagnose unit roots in the presence of no cross-sectional dependence. The LLC test assumes homogeneity in the autoregressive coefficients across panels, while the IPS test allows for heterogeneity, offering a more relaxed assumption structure. These tests were conducted to test the null hypothesis of no stationarity against the alternative of no unit root. The generic equation for Levin, Lin and Chu unit root test is:

$$\Delta y_{it} = \alpha_i + \rho y_{i,t-1} + \sum_{j=1}^{p} \beta_{ij} \Delta y_{i,t-j} + \epsilon_{it}$$

where: Δy_{it}measure the first difference of the variable y for country i at time t.; α_i is the unit-specific intercept (fixed effects); ρ captures the common autoregressive coefficient which is the same across all units in LLC; $y_{i,t-1}$ is the Lagged level of y; β_{ij} represents the coefficients for lagged first differences (to control for serial correlation); P is the number of lags included and ϵ_{it} captures the error term.

Given the dynamic nature of the model, the Hausman test was employed to determine the preferred estimator between PMG and MG. The PMG estimator imposes homogeneity on the long-run coefficients but allows for heterogeneity in short-run dynamics and error

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variances, whereas the MG estimator averages the coefficients after evaluating separate regressions for each cross-sectional unit. Assuming that the long-run parameters are homogenous across panels, this test has its null hypothesis in favor of the PMG estimator.

The Hausman test is stated in its general form as:

$$H = (\widehat{\beta}_{MG} - \widehat{\beta}_{PMG})' \left[Var(\widehat{\beta}_{MG}) - Var(\widehat{\beta}_{PMG}) \right]^{-1} (\widehat{\beta}_{MG} - \widehat{\beta}_{PMG})$$

where: $\widehat{\beta}_{MG}$ = coefficient vector estimated using the Mean Group estimator; $\widehat{\beta}_{PMG}$ = coefficient vector estimated using the pooled Mean Group estimator; $Var(\widehat{\beta})$ = estimated variance – covariance matrix of the respective estimator; H = Hausman statistic (distributed chi-square under the null hypothesis).

Panel cointegration test

This study tested for cointegration to determine the presence of long-run equilibrium relationship among the variables across the panel members. This procedure is important to justify the estimation and analysis of the long-run coefficients in Panel ARDL. The study employed the Pedroni cointegration test and controlled for robustness using the Kao method for panel cointegration. Both tests come with the null hypothesis that there is no cointegration among the variables. While the Pedroni procedure hypotheses in the alternative that cointegration exists but can vary across members (especially in group tests), the Kao test states that cointegration exists with a common relationship for all members (Kao, 1999; Pedroni, 2004). Pedroni considers the following panel regression model:

$$y_{it} = \alpha_i + \delta_i t + \beta_{1i} x_{1it} + \beta_{21i} x_{2it} + \ldots + \beta_{Mi} x_{Mit} + \ell_{it}$$

where: y_{it} is the dependent variable for unit *i* at time *t*; x_{Mit} captures the explanatory variables; α_i represent the individual fixed effects; $\delta_i t$ captures the individual time trends; ℓ_{it} is the error term which captures other variables not included in the model.

Results and discussion

Descriptive statistics and correlation matrix

In this study, the summary statistics about the distribution of the data on employed series is shown in *Table 2*. As could be observed, carbon footprint (CARBON) exhibits a mean value of 171,192.98 and a median of 67,782.72, suggestive of significant positive skewness. The standard deviation (230,246.56) corresponding to the reported mean points to a case of dispersion across the panel over the sampled period. The variables representing foreign direct investment (FDI), economic activity (ACT), renewable energy adoption (REN), and intellectual capital (ICA) display varying degrees of dispersion. This is suggestive of noticeable heterogeneity in the dataset.

Turning to the correlation matrix, generally weak to moderate magnitude in the relationship among the variables are isolated. For instance, a uniformly negative but relatively low, correlation between Carbon footprint and the other independent

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variables is revealed, with values ranging from -0.012 (with lnICA) to -0.314 (with lnREN). This suggests that higher renewable energy adoption and better intellectual capital correlate with lower carbon footprint, although the strength of these relationships is modest.

The assessment for traces of multicollinearity is of particular interest for model specification. For emphasis, when correlation coefficients between explanatory variables exceed 0.8 in absolute terms, multicollinearity typically becomes a concern. In this case, although moderate, the pairwise correlation estimates do not approach conventional thresholds for multicollinearity as the highest observed correlation among the regressors is between FDI and lnICA (-0.42). Other correlations, such as those observed between FDI and ACT (0.212) and between lnREN and lnICA (0.281), are relatively low. Thus, no immediate evidence of serious multicollinearity among the explanatory variables is suggested based on the correlation matrix.

Table 2. *Descriptive statistics and correlation matrix*

Variable	lnCARBON	FDI	ACT	lnREN	lnICA
Mean	171193	13.17	2.63	22.34	72.8
Median	67782.7	2.98	2.55	17.6	76.99
Std Dev	230247	58.59	3.87	12.14	17.32
Min	2956.27	-360.35	-10.94	4.5	4.8
Max	975098	452.22	24.62	57.9	91.99
Skew	1.8405	3.2644	0.2509	0.954	-2.127
Kurt	2.4859	29.217	5.2107	0.134	5.0818
J-B Stat	230.17	10456.7	319.71	42.68	512.41
p-value	0	0	0	0	0
lnCARBON	1				
FDI	-0.132	1			
ACT	-0.148	0.212	1		
lnREN	-0.314	-0.189	-0.144	1	
lnICA	-0.012	-0.42	-0.106	0.281	1

Source: Author’s own work

Cross-sectional dependence test

Given the nature of the panel members with a common regional affinity, the study investigated to determine whether the data on the variables across the countries responded uniformly to inherent shocks. In other words, the CD test in the study checks whether shocks or disturbances in one country (or unit) are independent of those in another country (or unit). This is particularly important because of the globalized nature of national economies and European Union member states in particular. The Pesaran Cross-sectional dependence test is employed in the analysis and the result as shown in *Table 3* suggests the acceptance of the null hypothesis of cross-sectional independence. This conclusion is inferred from the evidence of p-values higher than 0.05. The study decides therefore that Shocks in one country do not spill over to others and Units are not correlated.

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Table 3. *Pesaran CD test*

Variable	CD Statistic	P-Value	Conclusion
lnCarbon	0.412	0.68	No CSD detected
Fdi	0.52	0.603	No CSD detected
Act	-0.278	0.781	No CSD detected
lnRen	0.35	0.725	No CSD detected
lnInt	-0.19	0.849	No CSD detected

Source: Author's compilation

Panel unit root and cointegration tests

Having confirmed the presence of cross-sectional independence in the panel dataset, this study further tests for stationarity using panel unit root procedures with aligning assumptions. Particularly, Levin et al. (2002) and Im et al. (2003). The assumption of cross-sectional independence in these first-generation unit root tests is consistent with the nature of data as shown in *Table 3*. In *Table 4,* the panel unit root result shows that all the variable were non-stationary using the LLC and the IPS in their level form. However, all the series turned stationary at first difference using both procedures.

Table 4. *LLC and IPS unit root tests*

Variable	LLC Stat	P-value	IPS Stat	P-value	LLC Stat (Diff)	P-value	IPS Stat (Diff)	P-value
lnCarbon	1.75	0.96	2.1	0.98	-8.5	0	-6.9	0
FDI	2.45	0.99	1.85	0.97	-7.6	0	-6.2	0
ACT	1.9	0.97	1.6	0.95	-7	0	-5.75	0
lnREN	2.05	0.98	2.2	0.98	-8.2	0	-6.8	0
lnICA	2.3	0.99	2.05	0.97	-7.8	0	-6.5	0

Source: Author's own work

In the face of evidence confirming the existence of stationarity at first difference for all the variables of this model, the study moves to test for long-run equilibrium relationship between the dependent and explanatory variables. The result of the Pedroni (2004) test presented in *Table 5* indicates the presence of cointegration as it provides evidence for the rejection of the null hypothesis. This decision is further confirmed by the estimates of the Kao (1999) procedure which also reject the null of no cointegration among the modelled variables. In *Table 5,* the Hausman test compares to determine whether the long-run slope homogeneity assumption in PMG is valid. In this study, the null hypothesis that the PMG is preferred over the MG and DFE is accepted.

Table 5. *Cointegration and Hausman tests*

Cointegration test			Hausman			
Test	Statistic	P-Value	Test	Statistic	P-Value	Decision
Pedroni	-4.35	0.0001	Hausman	5.23	0.27	Prefer PMG
Kao	-3.92	0.0005				

Source: Author's own work

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Panel ARDL analysis of the modelled relationship

Having decided for PMG based on the Hausman test result in *Table 6* the study proceeds to estimate the long-run coefficients derived from the panel ARDL model. These results shed light about the structural interactions environmental sustainability relative to the regressors across the 27 EU countries and the United Kingdom. Given that the variables are either in logarithmic form or expressed as percentages, the coefficients naturally lend themselves to an interpretation in terms of elasticities, which enhances the comparability and policy relevance of the findings.

Firstly, the elasticity of carbon footprint with respect to foreign direct investment is positive and statistically significant, with a coefficient of 0.0142. This implies that a 1% increase in FDI inflows (as a share of GDP) is associated with a 0.014% increase in long-run carbon footprint. Though seemingly modest, this effect reinforces earlier findings that foreign capital inflows particularly in sectors with high carbon intensity can exacerbate environmental degradation when not regulated effectively. This finding is consistent with Wang et al. (2023) who observed a positive relationship between FDI and carbon emissions for low-income countries.

The findings of this study also resonate with the Pollution Haven Hypothesis, which suggests that firms may relocate emissions-intensive production to countries with relatively lax environmental standards (Ozkan et al., 2023). While it could be observed that the EU has robust environmental policy framework, this outcome could be explained by the presence of intra-bloc variation in regulatory enforcement. Further, to attract foreign capital, particularly in newer or smaller EU economies, the competitive drive may, in some cases, outweigh environmental considerations.

As opposed to the preceding outcome, economic expansion, proxied by GDP growth rate, presents a negative and statistically significant relationship with carbon emissions, with an elasticity of -0.0343. This result may reflect a growth structure which increasingly favors low-carbon sectors such as services, technology, and green manufacturing, characteristic of the EU and UK. The finding offers empirical support to the downward-sloping portion of the Environmental Kuznets Curve (EKC), where, beyond a certain income threshold, economic growth is decoupled from environmental degradation as cleaner technologies and sterner environmental policies take effect (Ozkan, et al., 2023).

Further reinforcing the critical role of clean energy in the EU's decarbonization strategy is the statistically significant negative coefficient for renewable energy adoption. A coefficient of 0.134 indicates that a 1% increase in renewable energy share in total final energy consumption reduces carbon emissions by approximately 0.13% in the long run. Extensive extant empirical evidence demonstrates that transitioning energy systems, from fossil fuel dependency to renewables, lead to remarkable national carbon footprints declines (Ali and Kirikkaleli, 2022; Dong et al., 2021; Mukhtarov, et al., 2022; Saidi and Omri, 2020). These findings are consistent with the goals of ongoing policy efforts toward expanding solar, wind, and bioenergy capacity for a bloc like the EU, which has committed to carbon neutrality by 2050 under the European Green Deal.

Turning to intellectual capital, proxied by educational attainment, the long-run elasticity with respect to carbon footprint, is perhaps most perplexing. A 1% increase in all adult population aged 25+ completing upper secondary education is associated with a 2.65% increase in carbon footprint, with a coefficient of 2.6510, positive and significant. This contradicts the prevailing conventional thought that greater human intellectual capital promotes environmental awareness and raises innovation in clean technologies.

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This may however, reflect structural patterns, within the EU context, where educational expansion coincides with increased consumption, urbanization, and mobility.

Particularly in the absence of widespread behavioral shifts or green infrastructure, these are critical factors that can lead to higher emissions. Moreover, the proxy used here does not distinguish between types of education or fields of study. It is reasonable to infer that while educational attainment is rising at this level, it may not be adequately directed towards sustainability. Yoo (2020) found that advanced intellectual human capital is associated with carbon emissions reduction. This proxy for intellectual is however not advanced.

This finding agrees with studies that caution against over-generalizing the environmental benefits of education without considering its content, application, and integration into broader socio-economic systems. In a single analytical framework, Haq et al. (2024) found that while increased intellectual capital corresponds with reduced carbon emissions in the OECD countries, it does not correspond with reduced carbon emissions in the BRICS economies. This later finding is consistent with the result of a positive relationship between intellectual capital and carbon footprint in this study.

Table 6. *Panel ARDL result*

Long-run estimates					Shor-run estimates				
Dependent variable: (lnCARBON)					Dependent variable: Δ(lnCARBON)				
Variable	**Coefficient**	**Std. error**	**t-statistic**	**P-value**	**Variable**	**Coefficient**	**Std. error**	**t-statistic**	**P-value**
					ECT(-1)	-0.1803	0.0556	-3.24	0.0153
FDI	0.014195	0.0014	9.7944	0	(ΔFDI)	0.0033	0.0061	0.5469	0.5853
ACT	-0.034339	0.0063	-5.3866	0	(ΔACT)	-0.0024	0.0039	-0.6238	0.5337
lnREN	-0.133929	0.0614	-2.1808	0.0309	(ΔlnREN)	-1.0233	0.8204	-1.2473	0.2144
lnICA	2.651044	0.0456	58.04	0	(ΔlnICA)	4.484	3.8331	1.1697	0.2441

Source: Author's own work

In the results of the short-run panel ARDL model, applied across the 27-member countries of the EU and the UK, the study found the response of carbon footprint to the modelled macroeconomic and developmental indicators insignificant. In *Table 6,* the error correction term (ECT (-1)) to be negative (-0.1803) and statistically significant ($p = 0.0153$). This implies the carbon footprint adjusts by about 18% to correct for any long-run equilibrium observed in the previous year. The significance of the error correction term also serves to confirm the conclusion of long-run equilibrium relationship arrived using the cointegration tests.

Notably, the short-run coefficients for foreign direct investment (FDI), economic activity (ACT), renewable energy adoption (lnREN), and intellectual capital (lnICA) are all statistically insignificant, with p-values exceeding the 5% level of significance. The statistical insignificance of these variables in the short-run supports established theoretical intuitions in environmental and macroeconomic literature, underlining the structural inertia and policy frictions that often characterize short-run dynamics. For instance, the Environmental Kuznets Curve hypothesis (Grossman and Krueger, 1995) argues that environmental degradation with respect to growth (income) follows an inverted U-shape.

Initially, the curve rises with growth while declining as income and institutional development permits investment in cleaner technologies. This suggests therefore that short-run changes in GDP growth are unlikely to attract immediate reduction in emissions, particularly in economies undergoing structural transitioning like the EU.

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Although the Pollution Haven Hypothesis (Copeland and Taylor, 2003), argues that foreign capital may gravitate toward jurisdictions with lax environmental standards, the attainment of the harmful environmental effects is delayed. The statistically insignificant short-run coefficient of FDI is therefore consistent with the Pollution Haven Hypothesis.

Rogers (2003) argues that innovations, such as renewables, follow an S-shaped adoption curve. Slow uptake and infrastructure bottlenecks, which prevent immediate emissions reductions even as policy commitments increase characterize the initial phases of this curve. The muted role of renewable energy adoption in the short-run can also be theoretically justified through technology diffusion theory (Rogers, 2003). Therefore, the lack of short-run significance does not negate the long-term promise of renewables but rather reflects transitional inefficiencies and the time-intensive nature of energy system transformation. Similarly, in proposing the endogenous growth Theory, Romer (1990) attributes long-run growth to the accumulation of human capital and knowledge.

The short-run insignificance of intellectual capital is therefore consistent with endogenous growth theory. How education is oriented and applied defines whether its environmental dividends will be attained. If education is not deliberately designed to align with the goals of environmental consciousness or green innovation, environmental gains may not accrue. In such scenario, increases in educational attainment may inadvertently stimulate higher energy consumption, particularly among urbanized and affluent cohorts, thus neutralizing any immediate carbon benefits.

Conclusion

Environmental sustainability is not only a global concern. It is simply the most critical cross-cutting challenge of contemporary time, with its urgency transcending borders, ideologies and sectors. Perhaps in realization of this, the EU has domesticated efforts at attaining carbon neutrality by 2050 in the EU Green Deal while the UK Net Zero Strategy represents the consolidated programs of the United Kingdom. In this study, Panel ARDL regression was applied to data covering the 27-member countries of the EU and the UK from 2014 to 2023.

The study investigated the relationship between carbon footprint and FDI, economic activity, renewable energy adoption and intellectual capital. The long-run model found foreign direct investment to increase carbon footprint. However, carbon footprint emerged as a decreasing function of economic activity proxied by GDP annual growth (%). The study also found renewable energy adoption to significantly decrease carbon footprint in the panel. Surprisingly, against a priori expectation, the long-run panel estimates indicated that intellectual capital does not reduce carbon footprint in this panel of European countries. In the short-run, the study found all the explanatory to be insignificant in explaining changes in carbon footprint.

Based on these findings, the study recommends that these European countries should calibrate FDI policy with a climate lens. Specifically, governments of these nations should innovate FDI screening mechanisms to ensure that all inflows align with domestic environmental sustainability aspirations. The green led growth discernible from the findings should be reinforced to steady the positive path. In this regard, regions historically reliant on carbon-intensive activities should transition to sustainable production practices to ensure that growth across the entire region does not attract environmental concerns.

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There is also the need to deepen renewable energy adoption towards optimizing existing potential and capacity across the entire region. In the light of the unexpected positive relationship between intellectual capital and carbon footprint, there is the need to integrate sustainability literacy and climate ethics across all levels of education. This may require incentivizing curriculum reforms to support the United Nations Educational, Scientific and Cultural Organization (UNESCO) Education for Sustainable Development (ESD) framework.

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APPENDIX

Table A1. *European Union member states and year of ascension*

Current EU member states (27)	
Country	**Year of EU accession**
Austria	1995
Belgium	1958
Bulgaria	2007
Croatia	2013
Cyprus	2004
Czech Republic	2004
Denmark	1973
Estonia	2004
Finland	1995
France	1958
Germany	1958
Greece	1981
Hungary	2004
Ireland	1973
Italy	1958
Latvia	2004
Lithuania	2004
Luxembourg	1958
Malta	2004
Netherlands	1958
Poland	2004
Portugal	1986
Romania	2007
Slovakia	2004
Slovenia	2004
Spain	1986
Sweden	1995

Former member state		
Country	**Year of accession**	**Year of exit**
United Kingdom	1973	2020

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