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Impact of Public-Private Partnership and Technology Transfer on Environmental Sustainability

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Abstract

The current study analyzes the Environmental Kuznets Curve hypothesis by examining how asymmetric energies between material depletion and foreign direct investment and environmental degradation operated across the Organization of Islamic Cooperation countries from 1983 to 2024. The research implements critical environmental indicators CO_2 (Carbon dioxide) and CH_4 (Methane) and N_2O (Nitrous oxide) with ECF (Ecological footprint) to analyze greenhouse gas emissions' effects on environmental sustainability. The analysis based on panel data econometrics reveals asymmetric relationships between variables that affect CO2, N2O and CH4 emissions and ecological footprint (ECF). The results demonstrate that FDI promotes CO2 and N2O emissions but reduces CH4 emissions, which leads to overall environmental quality improvement in the future. The positive relationship of trade openness with environmental emissions dominates its protective mechanisms because industrial enlargement and resource utilization play the dominant role. The dual nature of economic growth becomes clear because rising rates lead to worse environmental conditions, but decreasing economic growth presents unpredictable results in terms of pollutant levels. The reduction of emissions occurs through urbanization processes, which shows stronger evidence than emissions due to energy consumption, thus requiring sustainable energy guidelines. The study provides essential information to policymakers about controlling FDI while establishing sustainable trading practices and adopting renewable power generation systems to decrease environmental degradation across OIC nations. The study demonstrates that governments need specific actions which combine the development of economies with environmentally sound practices

Keywords: Environmental Kuznets Curve (EKC), Energy Consumption, Foreign Direct Investment (FDI), Environmental Degradation, Greenhouse Gas Emissions, OIC Countries, Sustainable Development

Introduction

Foreign direct investment (FDI) is a panacea for economic development in developing and developed nations. The investment grows capital resources, modern technologies, and infrastructure development to provide a shield to the masses for basic needs (Khan et al., 2024).Therefore According to the "pollution haven hypothesis," research and multinational firms establish operations in areas with flexible environmental regulations to generate more pollution (Ahmed & Malik, 2023). The "pollution halo hypothesis" demonstrates that FDI develops natural value by introducing state-of-the-art clean technologies that host countries can use to operate sustainably (Rehman & Ali, 2023). The textile industry's foreign investment initiated sustainable practices, but its environmental deterioration exhibited dual consequences of FDI in Pakistan (Shah & Bashir, 2024). Research-based on the Environmental Kuznets Curve shows that economic expansion damages the environment before advanced technologies lead to environmental quality advancements (Nasir et al., 2024). Environmental degradation occurs from higher energy consumption and growing trade volumes, yet technologically advanced procedures can reduce these adverse effects during early industrialization (Zafar et al., 2023). Three primary factors of trade liberalization alongside urbanization, together with fossil fuel use, limit the ability of economic growth to achieve sustainability (Hassan & Wang, 2024). The extensive use of fossil fuels by Organization of Islamic Cooperation members within developing economies creates substantial greenhouse gas emissions, according to Ali and Rehman (2023). Numerous member states from the Organization of Islamic Cooperation have not achieved the objectives set by the Paris Agreement, according to SESRIC (2023) data. Evidence shows that natural resource exhaustion worsens environmental degradation; thus, authorities need stricter rules to manage FDI environmental effects, as Yasmeen et al. (2024) explain. Foreign direct investment and environment are connected through mirror of the Environmental Kuznets Curve (EKC). Researchers wrongly equated environmental sustainability with environmental quality throughout 2000, although these concepts maintain separate meanings. According to Shahbaz et al. (2020), environmental sustainability does not lead to growth in environmental quality, even though factors such as free trade, FDI, urbanization, energy consumption, financial sector development, non-renewable energy usage, and total economic expansion exist. Both energy consumption and FDI drive CO_2 emissions across OIC countries since trade activities increase with the enhancement of economic growth (Rahman & Alam, 2021). When developing nations accept FDI, they take on pollution-intensive operations, which generate environmental destruction, as described by the pollution haven hypothesis (Zhang et al., 2017). Fossil fuels coupled with gas, transport systems, and electrical utilities create primary emissions, making energy consumption the most important factor in environmental degradation (Khan et al., 2019). The Nonlinear Auto-Regressive Distributed Lag (NARDL) method evaluates complex variable relationships. Previous evaluations of macroeconomic environment links were unsuccessful in generating proper policies since they failed to adequately investigate asymmetrical effects (Pesaran et al., 2001). The study creates fundamental recommendations for policymakers involved in this domain through its research findings. OIC nations require the immediate deployment of low-carbon initiatives and sustainable financial support for solar power, wind power, and hydropower systems because CO_2, NO_2, and CH_4 emissions continue to rise (Sadorsky, 2011). The government must create penalties targeting industrial facilities producing heavy emissions and transportation sectors for environmental deterioration reduction (Al-Mulali et al., 2015). Environmental sustainability needs deforestation policy improvements and afforestation program development because ecological footprint measurements demonstrate growth. Audits from governments should implement strict regulations that mandate FDI inflows to demonstrate genuine environmental vigilance through green technology investments (Doytch & Uctum, 2016). Environmental safety requirements that investors fail to comply with should result in tax penalties and sanctions, as Omri and Kahouli (2014) explain. Environmental degradation worsens substantially in rich and poor nations because of the combined use of oil, gas, and electricity products and their development-enabling functions. Environmental air quality grows more harmful proportionally to rising energy consumption in various parts of the environment. The annual carbon dioxide emission levels of Iran and Saudi Arabia (as representatives of OIC countries) increased to 863.4 MT and 527.2 MT, according to BP Statistical Review (2017). Land stress increases due to urban development and high industrial transportation energy use levels, creating critical health conditions because of growing air pollution (World Bank, 2021). The investigation spans from 1980 to 2021 because OIC countries intensified environmental issues during the first decade of the 2000s. Industrial SO2 and NO2 pollution reached hazardous levels in 2018, damaging ecosystems while creating critical health problems for neighboring populations. Economic advancement in developing nations will be achieved through strong policies with strict environmental control measures and active governance to prevent environmental sustainability damage from economic progress. The economic consequences of FDI have been extensively researched, but developing economies still need more studies about its environmental impacts, and gaps exist in this field of inquiry. Research studies have only examined the Pollution Haven Hypothesis or the Pollution Halo Hypothesis separately while ignoring the diverse environmental impacts FDI creates between manufacturing, energy, and agricultural industries (Zafar & Hussain, 2023). Developing nations experience obstacles because their separate industrial regulations generate different ecological results. According to Nasir and Alam, developing countries such as Pakistan, India, and Bangladesh have differing opinions regarding their potential to achieve an environmental turning point, which marks economic growth and slowing down environmental damage (2024). The absence of evidence pointing to the turning point raises doubts about how lasting FDI growth will be since it could generate polluting levels that surpass what countries can handle. The FDI-environment relationship receives a primary analysis from linear econometric studies. The Nonlinear Autoregressive Distributed Lag (NARDL) model functions as a contemporary analytical approach to study asymmetric FDI effects on environmental quality within developing nations, according to Tariq and Javed (2024). Scholars produce more accurate policy suggestions by analyzing nonlinear effects in FDI-environmental research because the effects move outside standard linear patterns. Developing countries receive limited investigation into their commitment to international climate agreements, which includes the Paris Agreement, yet this level of adherence influences FDI-environmental connections (SESRIC, 2023). Pursuing economic expansion with sustainability goals becomes complicated for developing countries.

Literature review

Studies have thoroughly researched the effect of FDI on environmental quality since the inception of the Environmental Kuznets Curve (EKC) theory in the early 1990s. Empirical investigations on developing nations continue to generate fresh data about this subject. The authors Rahman et al. (2020) utilized the Vector Error Correction Model (VECM) to evaluate the FDI inflow's impact on sustainable development in Bangladesh. Economic growth receives extensive advantages from foreign direct investment despite these advantages creating environmental damage that causes sustainability issues. The study conducted by Wei et al. (2019) utilizing 121 empirical studies revealed that FDI helps generate environmental advantages through pollution reduction programs while environmental development faces limitations unless green total factor productivity improves. Through their studies, multiple researchers have thoroughly examined the correlations between economic development and environmental conservation. The exploration of environmental quality concerning GDP growth and NAFTA trade by Grossman and Krueger (1991) established initial theoretical backing for the EKC hypothesis. Empirically tested evidence by Shafik and Bandyopadhyay (1992) established a tangible link between GDP growth and environmental outcomes. New scientific investigations prove the initial results that studied this exact topic wrong. EKC fails to produce precise environmental forecasts when economies grow, according to Frankel and Rose (2005), particularly for SO_2 and CO_2 emissions. Recent scientific investigations have adopted nitrous oxide (N_2O) emission assessments because they extend the tools used for environmental quality assessment. According to Zambrano-Monserrate and Fernández (2017), German N_2O emissions research shows that rising national income produces more N_2O pollutants while potentially creating advanced technology to benefit the environment. Manuscripts from recent academic publications have focused on the environmental sustainability effects of trade openness. As Udeagha and Ngepah (2019) and Pradhan et al. (2023) show, environmental advantages from trade liberalization derive from improved technology development and strict regulatory frameworks. Kellenberg and Mobarak (2008) produced research findings that contradict previous investigations documenting increased CO_2 emissions and SO_2, NO_2, and volatile organic compounds (VOCs) emissions that lead to deteriorated environmental conditions from expanded trade operations. The research used the PHH hypothesis to explore trade-lowering environmental quality links and led to conflicting outcomes between Bunje et al. (2022) and A1-Mulali et al. (2015), Jobert et al. (2019). Through Antweiler et al.'s (2001) investigation using composite effect and scale techniques, the authors showed that trade brings environmental improvements, given that specific economic conditions exist. The relationship between trade and the environment in OECD economies became significant to Cole (2004), who discovered their position as pollution-based rural territories because of strict environmental policies and technical strength. Many researchers have studied how trade openness affects environmental sustainability, specifically in developing nations. Yılancı et al. (2022) selected sulfur dioxide (SO_2) and carbon dioxide (CO_2) to analyze environmental pollution levels, with results showing consistency for countries under OECD and non-OECD. The analysis by Weili et al. (2022) involved 176 countries to establish that trade openness achieves positive environmental performance results by combining with high institutional standards. Based on their findings, the authors utilized the Two-Step System GMM to demonstrate positive connections between trade and environmental quality (2022). Trade openness creates a strong connection to environmental pollution, according to Ibrahim et al. (2022), by generating adverse effects on environmental quality. Many studies investigate how economic development relates to trade freedom for environmental quality, yet their findings do not match. Economic growth from trade openness leads to environmental deterioration throughout developing countries, according to the studies conducted by Copeland and Taylor (2005), Ling et al. (2015), and Kang et al. (2021). The research partnership between Murthy and Gambhir (2017) utilized the Environmental Kuznets Curve, but Ben Jebli et al. (2022) based their analysis on CO_2 emissions. The study conducted by Dogan and Turkekul (2016) evaluated CO_2 emission impacts on environmental quality through analysis of American data points from 1960 to 2010. According to the research findings, the presence of energy use is a fundamental requirement to prove the validity of the EKC hypothesis. Studies conducted within specific regions confirm that this link appears in different operational forms. An Autoregressive Distributed Lag (ARDL) model between 1980 and 2011 served Mrabet and Alsamara (2017) to study the trade-environment relationship in Qatar. Research shows environmental deterioration from CO_2 emissions exists, yet the ecological footprint represents a superior method to validate the EKC hypothesis. In their study, Uddin et al. (2017) demonstrated that higher GDP growth triggers increased ecological footprints, which poses foreign environmental agreements to face conflicting challenges. European economy-related research from the recent period has produced fresh investigative information. Aydin and Turan (2020) used the Panel Smooth Transition Regression (PSTR) model to analyze how 26 European Union member nations show CO_2 emissions developing nonlinearly alongside GDP growth. Economic growth triggers environmental deterioration first, but continuous economic expansion generates positive environmental results, according to the EKC theory. Ali et al. (2020a, 2020b) used their research to study FDI and trade openness variables and institutional quality in the countries affiliated with the Organization of Islamic Cooperation. Research conducted by the authors shows that economic development creates environmental degradation while institutional performance and FDI, together with urbanization development progress, accelerate this deterioration. The research investigates previous findings that are unclear by examining energy consumption alongside FDI and trade openness and several essential determinants that affect environmental degradation throughout developing nations. The findings created from this research provide essential knowledge to support executives who pursue environmentally focused economic development and environmental risk mitigation strategies.

Data Methodology

The scientific investigation of FDI and environmental quality connections analyzes them through the lens of the EKC hypothesis within countries grouped under the Organization of Islamic Cooperation. The EKC approach illustrates how pollution levels increase as incomes rise until they eventually decrease at specified income levels. The authors executed research using the Organization of Islamic Cooperation territories to analyze FDI effects on environmental quality by testing ecological footprint, methane, nitrous oxide, and greenhouse gas emissions. The independent econometric model considers environmental degradation through distinct analysis frameworks because multiple techniques exist to evaluate its diverse aspects. Research tracks greenhouse gas emissions while studying their response to FDI and considering the components of EG, EC, trade openness, and urbanization. Analytical research explains that CO_2 emissions cause more severe environmental damage than both CH_4 and N_2O emissions (SESRIC, 2018). Three main industrial sectors - transportation, energy, and industrial use emit CO_2 emissions at dangerously high levels in developing nations (Wang et al., 2020). Scientific research analysis clearly documents the environmental outcomes that develop from various economic activities. Research by Yusuf et al. (2020), indicates that agricultural practices create most N_2O emissions, but natural gas, coal, and oil fossil fuels are responsible for CH_4 releases. Results from the research deliver vital information to developing economies reliant on natural resources because their fast industrial development and city expansion produce heightened environmental stresses. A feature of the ecological footprint above classic measurement methods stems from its integration of complete indicators that analyze natural resource sustainability alongside biological capacity abilities in individual nations. The research examines FDI inflows and their economic growth impacts on environmental deterioration through 41 years, from 1983 to 2024. The study employs state-of-the-art econometric techniques to derive original insights regarding FDI flow effects on sustainable environmental results and pollution control in developing economic regions.

Econometric modeling

$$\Delta Epi_{it} = \theta_0 + \sum_{J=1}^{l} \psi_1 \Delta Ep_{it-1} \sum_{J=0}^{l} \psi_2 \Delta FDI_{it-j} + + \sum_{J=0}^{l} \psi_3 \Delta TOP_{it-j}$$
$$+ \sum_{J=0}^{l} \psi_4 \Delta EG_{it-j} + \sum_{J=0}^{l} \psi_5 \Delta URB_{it-j} + + \sum_{J=0}^{l} \psi_6 \Delta Ec_{it-j}$$
$$+ \gamma_1 lnEp_{it-1} + \gamma_2 lnFDI_{it-1} + \gamma_3 lnTO_{it-1}$$
$$+ \gamma_4 lnEG_{it-1} + \gamma_5 lnURB_{it-1} + \gamma_5 lnEC_{it-1} + \varepsilon_{it}$$

Table 01- Summarizing the Variables, Symbols, Measurement Units, and Data Sources

Variable	Symbol	Measurement	Data Source
Environmental Pollution	**CO_2**	Metric tons per capita	World Bank
Nitrous Oxide	**N_2O**	Thousd metric tons of CO_2 equivalent	WB
Methane Levels	**CH_4**	Thoud metric tons of CO_2 equivalent	WB
Carbon Footprint	**ECF**	Global hectares	Global Footprint Network
Forgn Direct Invet	**FDI**	Inflow of forgn invest (% of GDP)	W**B**
Trade 0penss	**TOP**	Sum of imports and exports (% of GDP)	WB
Econmic Grwth	**EG**	Sustned 2010 US$ (constant)	WB
Urbnization	**URB**	Total people living in urban areas (% of total population)	WB
Energy Comption	**EC**	Thsond metric tons of oil equivalent	WB

Trade Transparency, EG, FDI

The study examines the extended linear connection that exists between trade transparency indicators (TOP) and economic growth (EG) and foreign direct investment (FDI). The analysis investigates URB and the impact of URB on EP and EC as well as its relationship with TOP and EG and FDI (Ali et al., 2020a, 2020b).

Cross-Sectional Dependence Test

Cross-sectional dependence test

The study utilizes the CSD test by Pesaran (2021) which explains the balanced and unbalanced panels vigorously. The following equation represents CSD test statistics:

$$CSD = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij} \hat{\rho}_{ij}^{2} \rightarrow N(0,1) \qquad (2)$$

CIPS Analysis as a Panel Unit Root Test

The CIPS-panel unit root test of the second-generation stands as the preferred choice for detecting unit roots in the literature compared to first-generation unit root tests. Most literature in traditional research relies on first-generation unit root tests while assuming both homogeneity and independent cross-sections. First-generation tests show limitations because they can identify neither heterogeneity nor cross-sectional dependence thus leading to problematic or incorrect findings. Research studies have demonstrated second-generation CIPS tests outperform first-generation tests because they properly incorporate cross-sectional dependence (CSD) together with heterogeneity (Pesaran, 2007). This functional model describes variable relationships:

EP = f(FDI, TOP, EG, URB, EC)

Revised Panel Nonlinear ARDL Model

Time series data analysis with the Autoregressive Distributed Lag (ARDL) approach is used within extensive literature to research climate damage from energy consumption while including other regulatory variables. The study of FDI's environmental pollution impacts has used traditional methods including Granger causality testing as well as vector error correction models and standard ARDL methods as described by Wang et al. (2013). The exploration of both long- and short-run integrations by symmetric ARDL techniques has been carried out in recent studies (e.g., Fatima et al., 2021) while their analysis stops short of analyzing variable nonlinear connections. Artificial intelligence as well as green finance and institutional quality and ICT-based technologies operate under non-linear patterns.

yit= β0 + β1 xit + εit

The dependent variable of environmental pollution corresponds to yit while all other factors excluding foreign direct investment and openness to trade and economic growth rate and urbanization trends and energy usage fall under the category of independent variables denoted as xit at time t. The co-integration (ARDL) contains the following variables.

$$\Delta y_t = \alpha_0 + \alpha_1 y_{it-1} + \alpha_2 x_{it-1} + \sum_{j=1}^{m-1} \alpha_3 y_{it-i} + \sum_{i=1}^{m-1} \alpha_4 \Delta x_{it-i} + \varepsilon_{it} \quad (4)$$

where α_1 and α_2 express long-run coefficients and α_3 and α_4 as short-run coefficients, and m denotes optimal lag as per

Schwarz Information Criteria (SIC). According to Pesaran et al (2001) through ARDL the 1= 2 = 0 relation shows no evidence of co-integration in the long term. The method can function with I(0) orders or with I(1) parameter stability and also when parameters are stable at I(1) together with I(0) orders. The classic ARDL method does not produce appropriate results when dealing with data that follows order I(2). According to Granger and Yoon (2002) the symmetric approach produces wrong results when identifying unknown co-integrations because it fails to uncover the sign of variable interactions. The investigation of long and short-term NARDL interactions involved both positive and negative impact testing of the variables according to Shin et al. (2014). The co-integration NARDL regression model must start with:

$$Y_{it} = \beta_0 + \beta^+ x^+_{it} + \beta^- x^-_{it} + \varepsilon_{it}$$

$$X_{it} = x_0 + x^+_{it} + x^-_{it}$$

At time $t = 0$ the initial value is $x0$ and the formulas integrate positive and negative independent variable effects through $x+ t$ and $x- t$. Thus, Eqs. The analysis through (7) and (8) serves to calculate the total changes in variables FDI and TOP, as well as variables EG, URB, and EC.

- $x^+ = \Sigma_{i=1}^{t} \Delta x^+_{it} = \Sigma_{i=1}^{t} \max(\Delta x_i, 0)$
- $x^- = \Sigma_{i=1}^{t} \Delta x^-_{i} = \Sigma_{i=1}^{t} \min(\Delta x_i, 0)$

Three equation 3,4, and 7 induce the nonlinear ARDL model, as surveys (Ch0wdhury et al. 2021);

$$\Delta y_{it} = \beta_0 + \beta_1 y_{it-1} + \beta_2 x^+_{it-1} + \beta_3 x^-_{it-1} + \Sigma_{i=1}^{m-1} \beta_4 \Delta y_{it-i} + \Sigma_{i=1}^{m-1} \beta_5 \Delta x^+_{it-i} + \Sigma_{i=1}^{m-1} \beta_6 \Delta x^-_{it-i} + \varepsilon_i$$

The symbol Δ represents variable change and numbers 1 , 2 , and 3 represent long-run coefficients whereas $\alpha 3$, $\alpha 4$, and $\alpha 5$ represent short-run coefficients in the NARDL time series model framework. However nonlinear ARDL model considers.The nonlinear ARDL methodology calculates dynamic NARDL cumulative multipliers and illustrates positive ($x+ t$) and negative ($x- t$) exogenous variable effects when using the change in $x+$ or $x-$ by one unit (Rahman et al. 2022).

Dynamic panel NARDL approach

The nonlinear ARDL model estimates the dynamic cumulative multiplier NARDL and draws the positive and negative effects of exogenous variables, for instance, x_t^+ and x_t^-, respectively, which refer to change in one unit of x_t (Rahman et al. 2022).

$$c_1^+ = \sum_{j}^{m} \frac{\partial x_{it-j}}{\partial x^+_{it}}$$

$$c_1^- = \sum_{j=0}^{m} \frac{dx_{it-j}}{dx^-_{it}} \quad m = 0, 1, 2, 3, 4 \ldots \ldots$$

Note, since $m \to \infty$, then$c_1^+ \to \alpha^+$and$c_1^- \to \alpha^-$, where α^+ and α^- have a nonlinear long-term coefficient drive like evolves:

$$C^+ = \frac{-\theta^+}{m} \text{and} C^- = \frac{-\theta^-}{m}$$

$$EI = x_0 + 1GDP + 2GDP2 + \varepsilon_i$$

Researchers have assessed the validity criteria of the "Environmental Kuznets Curve" using data from Eq. (10). The validity test for the "Environmental Kuznets Curve" occurs through Eq. (10) while its differentiation depends on GDP levels.

$$dEI / dGDP = \beta_1 + \beta_2 * GDP$$

Now, we take the 2nd derivation of Eq.

$$d^2EI / dGDP^2 = \beta 2$$

The coefficient $\beta 20$ indicates that both local minima exist as well as establishes that EKC follows a U-shaped pattern. This study determines the threshold point of EKC by using Eq. (11). The threshold point equals zero according to Eq. (11) so we apply it to determine GDP values. The local minimum exists at $\beta 20$ where U-shaped EKC can also be found. The analysis derived EKC threshold value through Eq. (11) in this study. The study finds the threshold point of EKC by solving Eq. (11) for GDP when the value equals 0

$$\beta 1+2\ 2GDP=0$$

$$GDP^* = -\beta 1 / (2 * \beta 2)$$

The fundamental "Environmental Kuznets Curve" receives additional support through incorporation of new variables and endorsement of its environmental Kuznets curve framework. The model in (10) has been subdivided into four distinct versions. Studies by Aydin and Turan (2020) and Rahman et al. (2017) established several environmental contamination indicators as the dependent measurements of this research. It further separates into four distinct models when several variables are added alongside the environmental Kuznets curve concept that serves as underlying basis. Different types of proxies were implemented in this research.

$$\ln (CO2_{it}) = \alpha i \ln(CO2_{it-1}) + \beta i\, X_{it} + \Sigma_{Q=0}^{T} \gamma_{iQ} X_{t-Q} + \Sigma_{Q=0}^{T} \delta_{iQ} Y_{t-Q} + \varepsilon_{it} \text{---M1}$$

$$\ln (N2O_{it}) = \alpha i \ln(N2O_{it-1}) + \beta i\, X_{it} + \Sigma_{Q=0}^{T} \gamma_{iQ} X_{t-Q} + \Sigma_{Q=0}^{T} \delta_{iQ} Y_{t-Q} + e_{it} \text{-----M2}$$

$$\ln (CH4_{it}) = \alpha i \ln (CH4_{it-1}) + \beta i\, X_{it} + \Sigma_{Q=0}^{T} \gamma_{iQ} X_{t-Q} + \Sigma_{Q=0}^{T} \delta_{iQ} Y_{t-Q} + \varepsilon_{it} \text{---Model-3}$$

$$\ln (ECF_{it}) = \alpha i \ln(ECF_{it-1}) + \beta i\, X_{it} + \Sigma_{Q=0}^{T} \gamma_{iQ} X_{t-Q} + \Sigma_{Q=0}^{T} \delta_{iQ} Y_{t-Q} + v_{it} \text{-----------------------Model-4}$$

- **Functional Forms of All Models**

To examines two distinct parts of dependent variables: CO2 emissions and N2O emissions as nitrous oxide and CH4 as methane emissions and ECF as ecological footprints. The study employs foreign direct investment (FDI) and trade openness (TOP) as well as economic growth (EG) and urbanization (URB) and energy consumption (EC) as its independent variables in this analysis.

Table 2 Functional forms of all models

Functional forms	Model no
$CO_2 = (FDI, TOP, EG, URB, EC)$	Model no 1
$N_2O = (FDI, TOP, EG, URB, EC)$	Model no 2
$CH_4 = (FDI, TOP, EG, URB, EC)$	Model no 3
$EFC = (FDI, TOP, EG, URB, EC)$	Model no 4

CO_2, N_2O, CH_4, and ECF refer to carbon emissions, nitrous oxide, methane emissions, and ecological foot prints (ECF), respectively, and are dependent variables. Whereas foreign direct investment (FDI), trade openness (TOP), economic growth (EG), urbanization (URG), and energy consumption (EC) are independent variables

.

Table 2: CIPS-Test as Panel for Stationary

Variables	At Level	1st Difference
CO2	.003***	.000***
N2O	.018**	.011**
CH4	.013**	.055*
ECF	0.670	.002**
FDI	0.022**	.000***
TOP	0.058*	.000***
EG	0.037**	.018***
URB	0.023**	.000**
EC	0.235	.000***

Table -3 displays panel non-linear short-run evaluation results regarding OIC countries. In Model-1, the coefficients that show the relationship between foreign direct investment turn statistically significant at the 10% level for the positive aspect (−0.026) and at the 1% level for the negative aspect (+0.118).

The results indicate an asymmetric link between the analyzed variables. The increase in Foreign Direct Investment (FDI) by 1% results in a 0.026% decrease in CO_2 emissions among OIC countries because it leads to the implementation of clean advanced technology. A 1% decrease in FDI generates a 0.118% increase in CO_2 pollution in OIC countries according to Ali et al. (2020). International trade (TOP) shows different effects on CO_2 emissions, with coefficients of 0.815 and −0.041. The research reveals that CO_2 emissions in OIC countries rise by 0.815% when TOP increases by 1%, while a 1% decline in TOP produces a −0.041% reduction in CO_2 emissions. This supports the pollution haven hypothesis, as trade openness increases pollution in developing nations when host countries enter these areas to obtain profits (Appiah et al., 2022). The analysis demonstrates that economic growth (GDP) results in both positive and negative effects on CO_2 emissions (0.061 and −0.119). Moreover, the negative impact of economic growth (−0.119) achieves statistical significance at 5%. This indicates that, according to EKC theory, increased 1% increase in economic growth. While. increases CO_2 emissions by 0.061%, yet in the second stage, CO_2 emissions decrease as nations implement more advanced, cleaner technologies, leading to a −0.119% reduction in CO_2 emissions in OIC countries. The analysis shows urbanization (URB) has no significant connection to CO_2 emissions in the short term, as both coefficients (0.052 and 0.108) turn insignificant. The impact of energy consumption (EC) shows a strong and significant relation to CO_2 emissions, with coefficients 0.568 and −0.043**.** A 1% increase in energy consumption leads to a 0.568% increase in CO_2 emissions, whereas a 1% reduction in energy consumption results in a −0.043% decrease in CO_2 emissions in OIC countries.

Table 3: CO_2 Emissions (Dependent Variable: CO_2)

Variable	Coefficient	Prob.*
Coint.Eq(−1)	−.592**	.048
“d(FDI,POS)”	−.026*	.068
“d(FDI,NEG)”	.118***	.007
“d(TOP,POS)”	.815***	.022
“d(TOP,NEG)”	−.041**	.028
“d(GDP,POS)”	.061	.016
“d(GDP,NEG)”	−0.119**	.049
“d(URB,POS)”	.052	.148
“d(URB,NEG)”	.108	.129
“d(EC,POS)”	.568***	.000
“d(EC,NEG)”	−.043**	.042
Constant(C)	.073**	.019

Table-4: Impact of Economic Variables on N_2O Emissions

Variable	**Coefficient**	**Prob.***
CointEq(−1)	−0.281**	0.031
d(FDI.POS)	−0.033*	0.061
d(FDI.NEG)	.029**	.041
d(TOP.POS)	.061*	.059
d(TOP.NEG)	.031*	.072
d(GDP.POS)	−.261*	.017
d(GD.NEG)	.014*	.016
d(URB.POS)	−0.018*	0.061
d(URB.NEG)	.031**	.057
d(EC.POS)	.031*	.069
d(EC.NEG)	.041**	.016
Constant.	−.063**	.026

Table-4 displays that FDI) demonstrates positive changes in FDI, which decrease N_2O environmental emissions by 0.033%. This indicates that FDI brings cleaner technology to emerging market environments. The analysis shows that FDI decreases at 0.029% when decreasing by 1%; thus, negative FDI shocks potentially pollute technology reliance. The results indicate that Trade Openness (TOP) has a positive effect on N_2O emissions with a 1% increase in TOP levels, which supports the Pollution Haven Hypothesis (PHH). Implementing negative TOP Shocks shows that increased trade openness leads to N_2O emission reduction by 0.031 percent since reduced trade presumably restricts polluting industries from migrating. Adopting cleaner technologies combined with better environmental regulations during GDP growth initiates a decrease of 0.261% in N_2O emissions per 1% increase in GDP. The economic slowing down caused by a 1% GDP drop results in higher N_2O emissions at 0.014% due to reduced investments in green technologies. The increase in urban population by 1% decreases N_2O emissions by 0.018%, which could be attributed to better resource management and improved infrastructure. The decrease of urbanization by 1 percent leads to increased N_2O emissions equal to 0.031 percent due to less efficient resource use from reduced urbanization levels. Energy consumption affects N_2O emissions such that each percentage increase of 1% produces a 0.031% increase in emissions due to environmental impacts from high energy usage. Improvements in energy consumption performance lead to a 0.041% decrease in N_2O emissions, thus demonstrating the need for efficient energy management. The basic N_2O emission level without external disturbances amounts to −0.063, as the constant value C indicates.

Table 5: CH_4 Emissions (Dependent Variable: CH_4)

Variable	Coefficient	Prob.*
CointEq.(−1)	−0.057**	0.041
d(FDI.POS)”	−0.531***	0.002
“d(FDI.NEG)”	.025*	0.081
d(TOP.POS)”	−.063**	0.004
“d(TOP.NEG)”	−0.281**	0.015
d(GDP.POS)”	.521**	.008
“d(GDP.NEG)”	−0.071*	0.064
“d(URB.POS)”	.033**	.023
“d(URB.NEG)”	0.096**	0.018
d(EC.POS)	.062**	0.045
d(EC.NEG)	−0.658***	.000
Constant (C)	0.023**	0.004

Table -05: The analysis in Model 3 reviews the impact that CH_4 emissions and macroeconomic indicators generate in the system. Research shows that FDI effects on CH_4 emissions follow movement patterns through negative -0.531 and positive 0.025 coefficients, which achieve statistical significance at the 1% level and 10% level, respectively. The short-term data shows that increased FDI creates a 0.531% decrease in CH_4 emissions levels, indicating that foreign investments enhance environmental quality. A 1% reduction in FDI results in a 0.025% increase in CH_4 emissions. Similarly, trade openness (TOP) exhibits both positive and negative effects on CH_4 emissions, with coefficients of -0.063 and -0.281, respectively. TOP emission reduction rates contrast with TOP elevation rates because an increase of 1% in TOP lowers CH_4 emissions by 0.063%**,** while a decrease of 1% reduces CH_4 emissions by 0.281% within the short term. The influence of economic growth (EG) on CH_4 emissions appears as a double effect, producing significant results of 0.521 and -0.071 at the 5% and 10% significance levels, respectively. A 1% increase in EG results in a 0.521% rise in CH_4 emissions, while a 1% decline in EG leads to a 0.071% decrease in CH_4 emissions in OIC countries. Urbanization (URB) shapes CH_4 emission levels through both positive and negative relationships, as the coefficients 0.033 and 0.096 stand statistically significant at the 5% level**.** CH_4 emissions rise by 0.033% when urbanization increases by 1%**,** while a 1% decrease in urbanization raises CH_4 emissions by 0.096% within OIC countries. Energy consumption (EC) proves to have a substantial impact on CH_4 emissions, as it reflects coefficients of 0.062 and -0.658**.** Environmental quality benefits from a 0.062% CH_4 emission increase per 1% rise in energy consumption, but a 1% decrease in EC significantly reduces CH_4 emissions by 0.658%.

Table 6: ECF (Dependent Variable: ECF)

Variable	Coefficient	Prob.*
Coint Eq..(−1)	−.231**	.051
“d(FDI.POS)”	.508*	0.079
“d(FDI.NEG)”	−.017**	.041
“d(TOP.POS)”	.041*	.089
“d(TOP.NEG)”	−.016**	.063
“d(GDP.POS)”	.025**	.031
“d(GDP.NEG)”	.631**	.026
“d(URB.POS)”	−.033**	.041
“d(URB.NEG)”	−.052**	.022
“d(EC.POS)”	−.512**	.015
“d(EC.NEG)”	.085**	.071
Constant (C)	.086*	.057

FDI and TOP) on ECF

The parameters for Model 4 show a positive FDI effect of 0.508, while adverse FDI effects reach 0.017, with statistical significance at the 10% and 5% levels, respectively. An additional 1% of FDI generates a 0.508% increase in ECF, while a 1% FDI reduction drops ECF levels by 0.017%. This suggests that foreign direct investment can contribute to environmental damage, though its negative effects remain relatively small, allowing policymakers to regulate FDI to mitigate ecological consequences. The analysis shows that trade openness (TOP), contributes positively to ECF, with coefficients of 0.041 and −0.016, where the significance levels reach **10%** and **5%**, respectively. A 1% increase in TOP leads to a 0.041% increase in ECF, while a 1% reduction in TOP results in a 0.016% decrease in ECF. The results suggest that higher trade levels lead to environmental degradation through increased industrial activity and resource usage. Economic growth (GDP) also exhibits asymmetric effects on the ecological footprint. The coefficients of 0.025 and 0.631 are statistically significant at the 5% level. A 1% increase in GDP leads to a 0.025% rise in ECF, while a 1% decline in GDP significantly increases ECF by 0.631%. These findings suggest that economic downturns have a disproportionately higher negative environmental impact, reinforcing the need for sustainable development policies. The statistical coefficients for urbanization (URB) range from −0.033 to −0.052, both significant at the 5% level. A 1% increase in URB reduces ECF by 0.033%, while a 1% decrease in URB results in a 0.052% reduction in ECF. These results indicate that urbanization plays a crucial role in reducing ecological footprint, though effective environmental policies are required to sustain this trend. Energy consumption (EC) has significant effects on ECF, with coefficients of −0.512 and 0.085, both significant at the 5% level. A 1% increase in EC reduces ECF by 0.512%, whereas a 1% decrease in EC increases ECF by **0.085%**. These findings highlight that reduced energy consumption provides significant environmental benefits, making energy conservation a vital strategy for sustainability.

Table 7: Panel NARDL Long-Run Results

Models	Variables	Model 1	Model 2	Model 3	Model 4
“FDI…POS”		.097*	.024**	-.294**	.019**
		(0.069)	(0.016)	(0.043)	(0.047)
“FDI.NEG”		0.258**	0.046**	-0.195**	-0.017**
		(0.052)	(0.038)	(0.013)	(0.059)
“TOP.POS”		0.862*	0.085**	-0.537**	0.356**
		(0.072)	(0.023)	(0.052)	(0.028)
“TOP.NEG”		0.164**	-0.482**	0.384*	-0.068*
		(0.002)	(0.055)	(0.068)	(0.082)
“GDP.POS”		0.327**	-0.019**	0.019**	0.317**
		(0.048)	(0.015)	(0.029)	(0.025)
“GDP.NEG”		0.043***	0.078**	-0.123**	0.062**
		(0.001)	(0.072)	(0.028)	(0.013)
“URB.POS”		-0.808**	-0.025**	-0.083**	-0.070*
		(0.019)	(0.039)	(0.044)	(0.092)
“URB.NEG”		-0.427*	0.054*	0.088**	0.032**
		(0.062)	(0.082)	(0.047)	(0.054)
“EC.POS”		0.057**	0.077**	0.026**	-0.762**
		(0.052)	(0.037)	(0.023)	(0.033)
EC…NEG		-0.323*	0.432**	0.352*	0.082**
		(0.063)	(0.002)	(0.092)	(0.003)
C		0.362**	0.474**	0.725**	0.228***
		(0.021)	(0.034)	(0.041)	(0.012)

The table 07 provides the analysis of the long-run panel nonlinear interaction between variables. Model 1 establishes significant coefficient relationships between FDI and environmental effects at 10% and 5% significance levels where the FDI influence equals 0.097 and 0.258, respectively. According to the positive effect, an FDI growth of 1% generates a 0.097% rise in CO2 emissions, yet the negative effect implies that a similar FDI decline of 1% produces a 0.258% decrease in CO2 emissions. The relationship between FDI and environmental quality is directly based on studies showing negative environmental impacts as stronger than positive ones. Policy initiatives that govern FDI exhibit support from research findings to control environmental deterioration and create sustainable practices. The Model 1 results show that both positive effects of trade openness (TOP) equal 0.862 while negative EFFECTS total 0.164 and maintain statistical significance. TOP changes by one percentage point, which affects CO2 pollution by 0.862 percentage points in either the upward or downward direction depending on the change in TOP. The research findings demonstrate that environmental degradation from trade openness is mainly caused by industrial growth and resource usage, thus bringing greater positive aspects than negative effects. The study indicates that Economic Growth shows 0.327 as a positive effect while the negative effect stands at 0.043, and both findings hold statistical significance at 5 percent. The CO2 emission levels change by 0.043% when EG drops by 1%, and they rise by 0.327% with a 1% increase in EG. URB has a negative impact on CO2 emissions, with significant coefficients of -0.808 and -0.427.

The study reveals that urbanization leads to environmental improvements, indicating that an increase in urbanization rates results in a reduction of CO_2 emissions by 0.808%, while a decrease in urbanization rates leads to a reduction of 0.427%. The study shows that energy consumption (EC) generates positive CO_2 effects of 0.057 while negative effects reach -0.323. Energy consumption changes by 1% directly affect CO_2 emissions levels positively and negatively as activity increases CO_2 emissions by 0.057% but decreases them by 0.323%. Model 2 demonstrates that FDI affects N_2O emissions with a combined effect of 0.024 positive and 0.046 negative influence, the significance of which is achieved at a 5% level. The N_2O emission levels rise by 0.024% when FDI increases by 1%, while a 1% FDI decrease lowers emissions by 0.046%. The analysis reveals that Trade openness (TOP) produces significant results with positive and negative coefficients at 5%, which stand at 0.085 and -0.482, respectively. An increase of 1% in TOP results in N_2O emission growth of 0.085%, but a corresponding decrease of 1% in TOP leads to a 0.482% reduction of N_2O emissions. The impact of economic growth (EG) on N_2O emissions follows a positive and negative nonlinear pattern that produces significant coefficients of -0.019 and 0.078 at the 5% level. When EG increases by 1%, the N_2O emission levels decrease by 0.019%, but a similar 1% reduction in EG causes a 0.078% increase in emissions. URB presents a dual effect on emissions through its coefficients since a 1% URB increase yields a 0.025% emission reduction, while a 1% URB decrease results in a 0.054% reduction. The two significant levels of N_2O emission change associated with energy consumption are 0.077 and 0.432. The N_2O emissions increase by 0.077% when EC rises by one percent, while a one percent decreases in EC results in a 0.432% emission reduction. The investigation of FDI impacts on CH_4 emissions takes place in Model 3. The study results indicate that effects measured at -0.294 and -0.195 are statistically significant at the 5% level. Emissions of CH_4 decrease by 0.294% when FDI increases by 1%, but emissions decrease by 0.195%, corresponding to a decrease of FDI by 1%. The coefficients for TOP indicate that both trade openness variables are statistically significant at 5% with values of -0.537 and 0.384. The gas emissions decrease by 0.537% when TOP increases by 1% yet decrease by 0.384% when TOP decreases by 1%. The parameters from the economic growth variable reveal a 0.019% increase in CH_4 emissions when EG rises by 1%, yet a -0.123% reduction when EG decreases by 1%. The quantified relationships of Urbanization reveal that when URB increases by 1%, the CH_4 emissions decline by 0.083%, but when URB decreases by 1%, the reductions reach 0.088%, respectively. The energy consumption variables yield two significant results: a 1% rise in EC causes a 0.026% increase, and a 1% decrease leads to a 0.352% emission decrease. The data from Model 4 demonstrates how FDI affects ecological footprint (ECF) through its inverse relationship along with an impact of 0.018 and -0.016 that reaches statistical significance at 5%. Each 1% boost in FDI produces a 0.018% expansion of ECF, and parallels, each 1% drop in FDI results in a 0.016% decrease in ECF values. Trade openness (TOP) exhibits coefficients of 0.355 and -0.068, which are significant at 10% and 5%, respectively. A reduction of 1% in TOP results in a change of 0.355% or 0.068% in ECF. The statistical analysis shows that economic growth (EG) makes noteworthy contributions to ECF because its coefficients are 0.317 and 0.062, reaching significance at 5%. The ECF volume rises by 0.317% when EG increases by 1% yet decreases by 0.062% when EG decreases by 1%. Urbanization (URB) has an inverse relationship with ECF since a percentage increase leads to a decrease of 0.070%, and a percentage decrease results in a reduction of 0.032% in ECF. The coefficients of -0.762 and 0.082 from energy consumption (EC) demonstrate that ECF decreases by 0.762% with each 1% EC increase, yet it reduces by 0.082% with every 1% EC decrease.

Conclusion

The study demonstrates through scientific evidence how the Environmental Kuznets Curve (EKC) hypothesis explains the uneven relationships between FDI and material consumption and energy usage regarding environmental damage situations. This research observes greenhouse gas emission patterns and environmental sustainability in Organization of Islamic Cooperation countries through the analysis of four key environmental indicators, including carbon emissions (CO_2), methane (CH_4), nitrous oxide (N_2O), and ecological footprint (ECF) over a span from 193 to 2024. Economic growth and its relationship with FDI exist in multiple directions throughout the Organization of Islamic Cooperation member states. A direct correlation exists between energy usage and environmental pollution because energy consumption is a principal factor in environmental deterioration. Numerous studies confirm that growing power consumption mainly from non-renewable energy sources leads to worse environmental pollution. The study emphasizes the need to examine supplementary elements that might reduce environmental pollution across OIC nations through technological advancement and sustainable development. These factors can disconnect the link between economic development and environmental damage, supporting sustainable development goals. Future academic investigations should measure the impact of these variables on environmental quality enhancement methods in nations belonging to the Organization of Islamic Cooperation. This work presents new knowledge about the unequal associations between EC and FDI and controlled factors on environmental pollution in OIC countries. The research contributions exist, but some limitations present future research opportunities. The study fails to assess other greenhouse emissions such as sulfur dioxide (SO2) and sulfur hexafluoride (SF6), perfluorocarbons (PFCs), and hydro fluorocarbons (HFCs) because necessary data remains unavailable. Future research should add these emissions to analytical models because doing so offers better environmental pollution assessment. The analysis includes only 49 member countries of the Organization of Islamic Cooperation because available data does not include all 57 states. Future research needs to include all member states of the Organization of Islamic Cooperation when their relevant data become publicly available. The current research fails to investigate how FDI affects different components of the Environmental Kuznets Curve (EKC), including competitive advantages, scaling effects, and combination effects. Future research should study particular environmental variables to produce more thorough insight into the relationship between FDI and the environment. The research findings substantially impact OIC country policies regarding sustainable development and environment management.

Recommendations and Policy Implementation

1. According to the study, Energy consumption leads to increased environmental pollution through CO2, N2O, and CH4 emissions in particular. Policymakers must select carbon-free projects, including solar energy-based initiatives, wind energy projects, and green transportation systems as a mitigation strategy. The combined efforts will decrease our dependence on fossil fuels since they lead to cleaner air and environmental sustainability.
2. The unrestricted growth of Trade Openness and FDI and their fundamental role in economic growth create environmental damage. Authorities should create strict regulations that control industrial operations by enforcing environmental requirements. The revenue obtained from punishing non-compliant industries should be redirected to funding environmental conservation programs, including the establishment of renewable energy systems and tree replantation initiatives.
3. The study shows that environmental pollutants decrease strongly when people decrease their ecological footprints while planting trees. The government is responsible for creating programs that fight deforestation and advance forest regeneration. Combining community forest management with reforestation efforts and sustainable land-use standards promotes environmental improvement and future greener conditions.
4. The research data shows that fossil fuel use will drain the atmosphere of quality air. The government should promote low-carbon-emission projects and sustainable funding solutions

to boost renewable energy expansion, specifically through solar power systems, wind energy, and hydroelectricity plants. Widespread policies need implementation to protect natural assets such as minerals, water sources, and land by maintaining sustainable use for future generations.

5. Integrating environmental aspects into economic policies maintains economic development while preserving the sustainability of the environment. Decision makers should merge ecological elements into their economic decision-making processes to maintain environmental sustainability throughout growth development. The sustainability process requires support for energy-efficient technology alongside sustainable urban development and environmentally friendly industrial industries.

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