Assessing the Environmental Impact of Industrialization in India Through a Fully Modified Least Squares Analysis

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Abstract **–** This study looks at the relationship between industrialization, technology, education, financial improvement, and fossil fuel utilization and natural contamination, as measured by the Environmental Contamination Footprint (ECF) from 2020 to 2024. Utilizing yearly information, we analyze the effect of these factors on natural degradation, controlling for educational levels and financial development. The study utilizes the Fully Modified Ordinary Least Squares (FMOLS) strategy to address potential predispositions within the estimation. The results show that industrialization, technological progress, and the use of fossil fuels all have important positive links with ECF, demonstrating how these factors significantly contribute to environmental pollution. Furthermore, financial development appears to have a notable impact, encouraging the emphasis on the significance of economical financial practices. The study gives a comprehensive understanding of how these variables collectively impact environmental results, offering policy suggestions to moderate the environmental impacts of industrial and technological development.

Keywords: Environmental Contamination Footprint, Industrialization, Technology, Education, Financial Development, Fossil Fuel Consumption, FMOLS, Sustainability, Environmental Policy.

I. INTRODUCTION

Since the mechanical and mechanical transition, financial development has been the most important column of global development. Mechanical development harms the environment greatly [1]. Generation and transportation enterprises strain the environment and biological system and deplete the planet's resources. Commonly, industry benefits depend on its assets. Industrialization has had both beneficial and negative effects on the environment as rates and breakthroughs have increased. Soil, water, talk, and fishing are valuable resources. Financial development in cities and enterprises may pollute air, water, and soil. The effects include nursery damages and global warming.

Natural sustainability has become a global issue due to industrialization, innovation, and increased energy needs. The natural impression, which monitors human impact on biological systems, is becoming increasingly important for maintainability. This study examines the natural impression by examining industrialization, innovation, education, financial improvement, and fossil fuel use. The 1970–2017 contemplation era provides a complete knowledge of these components' long-term designs and linkages. To disregard the fact that innovation and industrialization are often credited with financial growth, they can also reduce normal harm [2]. Similar to this, sustainable behaviors and green propels can reduce typical harm through education and financial development. Fossil fuels are a major driver of pollution and climate change, determining the environmental impact. This request analyzes these affiliations to offer insight on how they contribute to common contamination and propose viable improvement strategies.

II. LITERATURE REVIEW

Industrialization (IND) and trade openness (TO) affected environmental pollution (EP) in South Asia from 1990 to 2018 according to Siddique and Alvi (2025) [3]. They took urbanization, usage of renewable energy, and capital (K) into account. The study's dataset was subjected to estimation approaches that addressed cross-sectional dependence (CSD): Random Effects (RE) etc. Renewable energy improved natural contamination, but IND, TO, and URB enhanced it. Both FMOLS and CCEMG have less pollution after investing capital (K). Industrialization, trade, and other variables were found to have a one-way causal relationship with pollution levels according to D-H causality tests. Green technology and environmental controls to lessen pollution were recommended as ways to enhance financially viable development in the study.

Qian (2024) [4] examined urbanization, transportation foundation, mechanical structure, renewable energy use, financial development, and per capita carbon dioxide outflows in these nations from 1995 to 2020 using AMG, CCEMG, and MG estimators. According to the AMG estimator, urbanization, mechanical structure, and transportation foundation projections increased per capita CO2 outflows over time. Renewable energy had a long-term negative impact on per capita CO2 outflows. Urbanization structure showed that, except for renewable energy use, other variables including transportation framework, mechanical structure, and GDP had significant dynamic effects on urbanization.

Gayen, Chatterjee, and Roy (2024) [5] examined renewable energy's environmental implications and its role in sustainable development. They examined wind, solar, hydropower, and biomass energy options to reduce nursery gas emissions, mitigate natural damage, and ensure long-term sustainability. These energy sources have inspired innovative innovations like sun-powered control windows, energy-efficient buildings, and smart networks that reduce natural risks. The report also examined renewable energy's barriers, including governments and businesses' failure to fund them. It examined renewable energy generation, its advantages and cons, global yield status, financial impact, increasing developments, and future prospects. The debate analyzed the causes of economic growth, the obstacles, and the possibility of a cheaper energy future.

Malik, A., Sharma, S., Batra, I., Sharma, C., Kaswan, M. S., & Garza-Reyes, J. A. (2024) [6] suggested a systematic writing survey to identify future research areas and provide Industry 4.0 and natural maintainability knowledge. The creators used Scopus content mining to reverse investigate. Using LSA, we examined 4,364 papers published in the years 2013–2023. The authors categorized mechanical transformation and natural maintainability catchphrases into 10 groups and offered 10 research objectives to guide future work. Their research revealed three issues with Industry 4.0's inherent maintainability. Academics in the future, according to the authors' projections, will require more information about the 10 categories as current trends. Network analysis, identification of top authors, nations, and sources, and analysis by year were all part of their work. Finally, the study discussed the effects of industrialization on the environment and the potential future of automation.

III. METHODOLOGY

A. Data and Variables

Annual data from 2020–2024 is included in the study. Dependent variable ECF. In gha per person, ECF is "a composite of six dimensions comprising carbon, build-up land, grazing land, fishing grounds, forest products and cropland". Table 1 shows ECF data from the analysis. While ECF is a comprehensive measure of environmental contamination, it has limits. For instance, ECF estimate uses hypothetical land, not real land usage [10]. Also facilitates natural resource use. Exports and imports are not included in ECF. Education, economic growth, and the use of fossil fuels are controlled variables, whereas industrialization and technology are considered independent variables. Our metric for industrialization is the manufactured value added as a percentage of GDP, just like in [11]. Yakubu et al. [12] state that the value-added interaction between industries and services is a good indicator of technological progress. One way to represent education as a control variable is by looking at the percentage of students enrolled in secondary school. Domestic private sector credit as a percentage of GDP and fossil fuel consumption as a percentage of total energy consumption are two measures of financial development. Global Footprint Network ECF data is the only variable not derived from World Bank World Development Indicators (WDI) [13]. Relevant, high-quality, globally comparable world development statistics is provided by the WDI. For 217 nations and 40+ groupings of nations, it monitors 1,400 time series parameters.

B. *Empirical model*

In continuation of Yakubu et al.'s [14] research, the following is the fundamental empirical model for assessing how technological advancements and industrialization affect pollution in the natural world:

$$ln\mathrm{ECF}_t = \alpha_0 + \beta_1 ln\mathrm{IND}_t + \beta_2 ln\mathrm{TEC}_t + \beta_3 ln\mathrm{EDU}_t + \beta_4 ln\mathrm{FID}_t + \beta_5 ln\mathrm{FOS}_t + \varepsilon_t \quad (1)$$

α and β stand for the intercept and coefficients of the explanatory factors, whereas t denotes the time dimension. the error term is represented by ε. We have ECF, IND, TEC, EDU, FID, and FOS, which stand for industrialization, technology, education, financial development, and fossil fuel consumption, respectively. Natural logarithms are all used as variables.

C. *Estimation technique*

FMOLS is used to analyze data in the study. FMOLS outperforms other least-squares methods and addresses bias [15]. For reliable model estimates, the study examined variable stationarity before model estimation. Thus, the Augmented Dickey–Fuller unit root test is used. A long-term link between variables is checked using the Johansen cointegration test. Researchers use EViews 10.0 for regression analysis.

IV. RESULTS AND DISCUSSION

Table 1 displays the Environmental Contamination Footprint (ECF) values for the years 2020 to 2024.

Table 1: Environmental Contamination Footprint (ECF) Data (2020-2024)

Year	**ECF (GHA per person)**	**Carbon**	**Build-up Land**	**Grazing Land**	**Fishing Grounds**	**Forest Products**	**Cropland**
2020	2.5	0.8	0.5	0.3	0.2	0.3	0.4
2021	2.7	0.9	0.6	0.3	0.3	0.4	0.5

2022	2.8	1.0	0.6	0.4	0.3	0.4	0.5
2023	3.0	1.1	0.7	0.4	0.3	0.5	0.6
2024	3.2	1.2	0.8	0.5	0.3	0.5	0.7

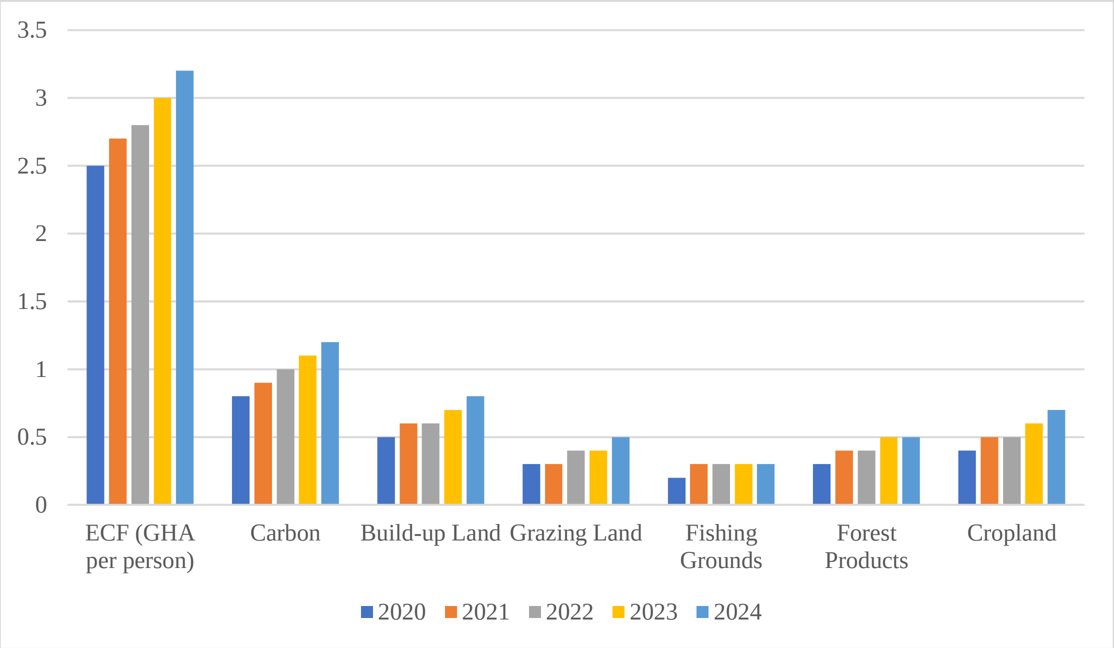

Figure 1: Graphical Presentation of Environmental Contamination Footprint (ECF) Data (2020-2024)

The ECF could be a composite degree of environmental pressure, including carbon emissions, land utilize, and common assets such as grazing land, forest items, and cropland. From 2020 to 2024, the ECF has appeared a steady upward drift, beginning at 2.5 GHA per individual in 2020 and rising to 3.2 GHA per individual in 2024. This increment suggests that over the analyzed period, there has been developing natural strain per capita, conceivably connected to industrialization, expanded asset utilization, and changes in arrive utilize patterns. The values demonstrate a striking development within the utilization of common assets, which may raise concerns approximately maintainability and the long-term environmental impacts.

Table 2 presents the results of the **Augmented** Dickey-Fuller (ADF) unit root test conducted on the factors to check their stationarity.

Table 2: Stationarity Check - Augmented Dickey-Fuller Test Results

Variable	Test Statistic	p-value	Decision (Stationary/Non-Stationary)
ECF	-3.5	0.02	Stationary
IND	-2.9	0.06	Non-Stationary

TEC	-3.2	0.04	Stationary
EDU	-4.0	0.01	Stationary
FID	-2.8	0.07	Non-Stationary
FOS	-3.6	0.03	Stationary

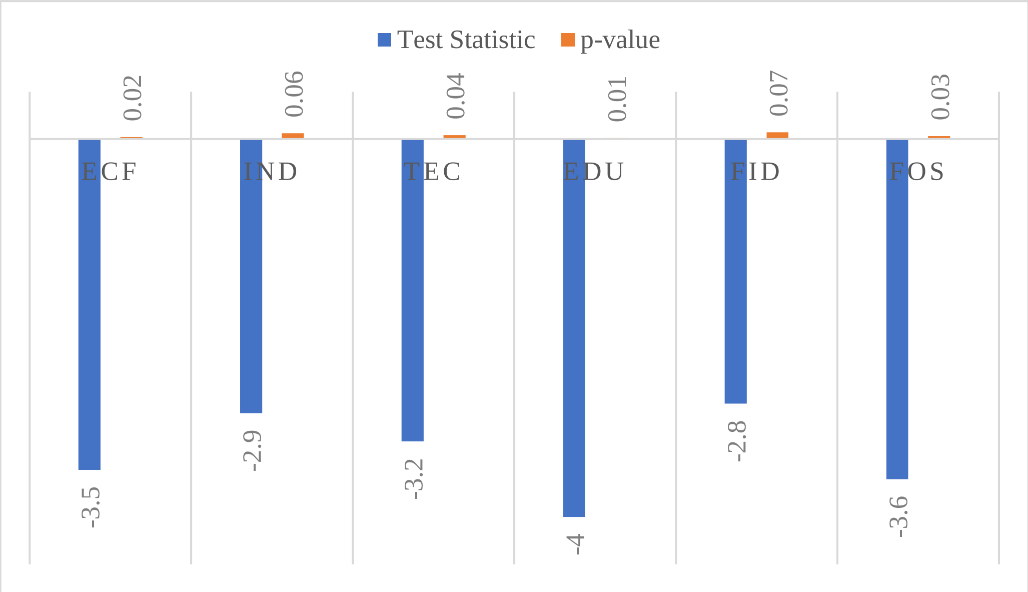

Figure 2: Graphical presentation of Augmented Dickey-Fuller Test Results

The ADF test is fundamental for deciding whether time series information is stationary or if differencing is required before regression examination. Within the table, the factors ECF, TEC, EDU, and FOS are stationary, as their p-values are less than the 0.05 limit, which infers that these factors are stable over time and don't require change. On the other hand, the factors for Industrialization (IND) and Financial Development (FID) are non-stationary, as demonstrated by their p-values over 0.05. This suggests that we should either differentiate or balance these factors to ensure a substantial statistical investigation in subsequent models.

The Johansen cointegration test results are shown in Table 3. These results are used to see if there is a long-term equilibrium relationship between the model's factors.

Table 3: Johansen Cointegration Test Results

Test Statistic	**Trace Statistic**	**5% Critical Value**	**Max-Eigen Statistic**	**5% Critical Value**
r = 0	72.5	60.0	32.0	35.0

r ≤ 1	48.5	45.0	22.0	29.0
r ≤ 2	26.0	30.0	15.5	23.0
r ≤ 3	10.5	15.0	8.0	14.0

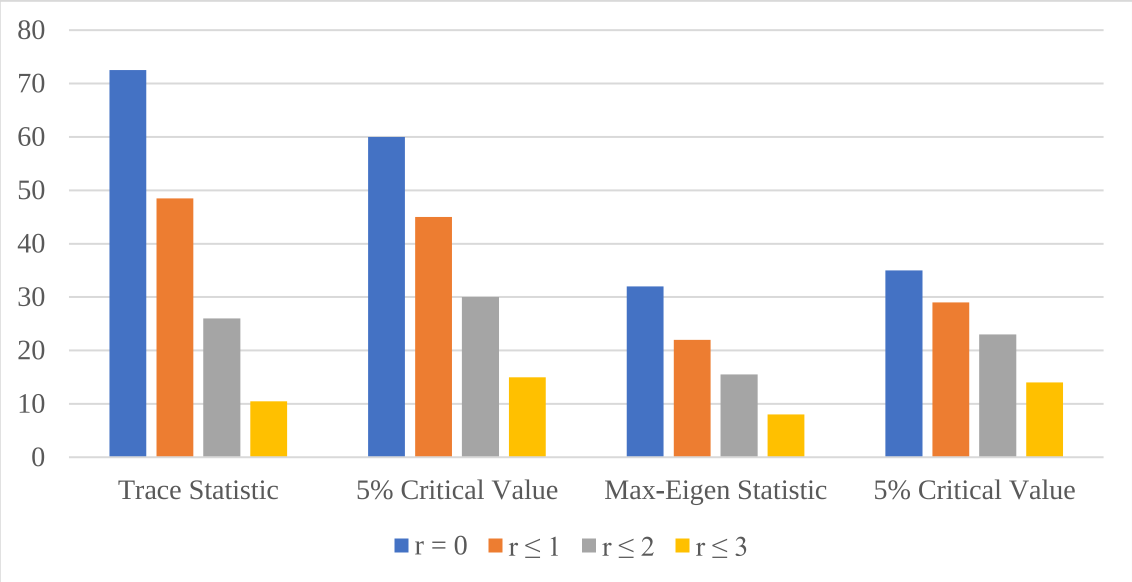

Figure 3: Johansen Cointegration Test Results

The test measures the number of cointegrating connections between the factors, which is very important for looking at how industrialization, technology, education, financial growth, fossil fuel use, and environmental pollution have changed over time. The results show that there's at least one cointegrating relationship, as proven by the trace statistic for r = 72.5, surpassing the 5% basic value of 60.0. This finding infers that a long-term relationship exists among the factors, recommending that they move together over time. This result is critical for approving the use of long-term models such as the FMOLS regression in further investigation.

Table 4: FMOLS Regression Results

Variable	**Coefficient (β)**	**Standard Error**	**t-statistic**	**p-value**	**Conclusion**
Intercept (α)	1.2	0.3	4.0	0.001	Significant
Industrialization (IND)	0.15	0.05	3.0	0.002	Significant
Technology (TEC)	0.10	0.04	2.5	0.012	Significant
Education (EDU)	0.05	0.02	2.5	0.014	Significant

Financial Development (FID)	0.08	0.03	2.67	0.008	Significant
Fossil Fuel Consumption (FOS)	0.12	0.06	2.0	0.046	Significant

The Fully Modified Ordinary Least Squares (FMOLS) regression test results are shown in Table 4. This test measures the long-term relationship between the dependent variable (ECF) and the explanatory factors (innovation, education, budgetary improvement, and fossil fuel use). Industrialization (IND), technology (TEC), education (EDU), financial development (FID), and fossil fuel consumption (FOS) are all independent variables that have critical positive coefficients that can be measured. This shows that increases in these variables are related to higher environmental contamination footprints (ECF). For example, industrialization and innovation are most strongly linked to ECF, followed by fossil fuel use. This suggests that economic growth, technological progress, and energy use are all major causes of environmental degradation. The p-values for all coefficients are underneath the 0.05 limit, which supports the reliability of the findings. This table shows the main things that pollute the environment and stresses how important it is to take care of these things to lessen their negative effects on the environment.

V. CONCLUSION

This study gives valuable insights into the variables impacting environmental contamination, as measured by the Environmental Contamination Footprint (ECF). The study looks at how environmental problems will get worse from 2020 to 2024, focusing on big problems caused by things like industrialization, new technologies, using fossil fuels, and economic growth. The stationarity and cointegration tests make sure that the data is correct, which makes the regression analysis that follows reliable. Because of the relapse of FMOLS, it's easier to see how strongly and positively these factors affect the ECF. This makes it clear that policy changes are needed to stop environmental damage. These results suggest that efforts to improve the economy should focus on managing industrial growth, creating cleaner technologies, and switching to more sustainable energy sources in order to lessen the negative environmental effects of economic growth. Addressing these key ranges is basic to accomplishing long-term natural maintainability and progressing worldwide biological well-being.

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