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The Impact of Chinese FDI on Carbon Emissions in Ethiopia: The Role of Institutional Quality

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Abstract- Ethiopia has emerged as a top destination for Chinese foreign direct investment (FDI) in Africa, yet the environmental implications remain inadequately understood. This study investigates the impact of Chinese FDI on carbon (CO_2) emissions in Ethiopia from 1991 to 2024, employing an autoregressive distributed lag (ARDL) bounds testing approach. We further examine the moderating role of institutional quality in shaping the FDI-emissions nexus. Results reveal a positive and statistically significant long-run effect of Chinese FDI on CO_2 emissions ($\beta = 0.0571$), providing empirical support for the Pollution Haven Hypothesis (PHH) in the Ethiopian context. However, institutional quality exerts a negative and significant moderating effect ($\beta = -0.2384$), suggesting that improved governance can substantially reduce the environmental burden of FDI. Toda-Yamamoto causality tests confirm unidirectional causality from Chinese FDI to CO_2 emissions, with no evidence of reverse causality. Control variables—energy consumption, industrialization, and economic growth—also exhibit significant positive effects on emissions. We conclude that Chinese FDI contributes to environmental degradation in Ethiopia, though this effect is mitigated by stronger institutional quality; thus, policies should prioritize enhancing environmental governance and regulatory enforcement to curb the ecological costs of investment-led growth.

Keywords: Chinese FDI, CO_2 Emissions, Pollution Haven Hypothesis, Institutional quality, Ethiopia, ARDL.

I. Introduction

Foreign Direct Investment (FDI) plays a vital role in advancing socio-economic development, especially in developing nations. It brings capital, technology, and job creation, enabling countries to integrate into global value chains (Githaiga & Kilong'i, 2023). In Sub-Saharan Africa, manufacturing and industrial parks through initiatives like the Belt and Road Initiative (BRI) and the Forum on China-Africa Cooperation (FOCAC) (Lisinge, 2020).China's FDI has become a key source of financing for national development (Adams et al., 2017). Ethiopia, for instance, has leveraged FDI to support its transition to a market-oriented economy since 1991. The country's reforms—such as market liberalization, infrastructure development, and the establishment of industrial parks—have made it one of the region's leading FDI destinations, particularly for China, (Barber & Pilling, 2019).

While the economic benefits of Chinese FDI—including job creation, infrastructure development, and productivity gains—are well-documented (Doku et al., 2017; Franco, 2012; Wozir & Luo, 2020), its environmental implications remain underexplored and debated. Existing literature presents conflicting views, with some suggesting that Chinese FDI contributes to the "pollution haven" effect, where weak environmental regulations attract polluting industries, while others argue for the "pollution halo" effect, where FDI leads to the adoption of cleaner technologies (Cole, 2004; Eskeland & Harrison, 2003). Global warming, one of the most pressing global challenges, poses significant threats to the planet and human well-being. Since the industrial revolution, human activities have significantly increased greenhouse gas (GHG) emissions, primarily through fossil fuel combustion, deforestation, agricultural practices, land-use changes, and industrial growth(Dogan & Seker, 2016; Engdaw, 2020).

In recent years, developing countries, including Ethiopia, have seen their CO_2 emissions surpass those of developed nations, now accounting for more than 50% of global CO_2 emissions (Martínez-Zarzoso & Maruotti, 2011). Ethiopia, specifically, though a relatively low emitter globally,has emerged as the third-largest emitter of CO_2 in East Africa, following Sudan and Kenya(Taka et al., 2020). As Ethiopia strives to grow economically, reduce income inequality, and mitigate climate change, it faces significant trade-offs. The country aims to become a middle-income nation while also reducing its greenhouse gas emissions by 64% below business-as-usual levels by 2030 (Hundie, 2021).

Although the economic benefits of FDI in Ethiopia are widely recognized, its environmental impacts—particularly in relation to Chinese FDI—are not well understood. While existing studies have examined the general relationship between FDI and CO_2 emissions, few have disaggregated the data by source country, with little attention paid to Chinese FDI specifically. Given that China is Ethiopia's largest FDI partner, especially in infrastructure and manufacturing, it is important to examine how Chinese investments may have distinct environmental effects compared to other foreign sources of capital(Tang et al., 2024). Some studies suggest that FDI can reduce CO_2 emissions, supporting the Pollution Halo Hypothesis (Ayalew, 2021), while others show a positive relationship between FDI and emissions, consistent with the Pollution Haven Hypothesis. Furthermore, most studies do not consider the role of institutional quality, which can significantly influence the environmental impact of FDI.

Institutional quality—comprising regulatory effectiveness, political stability, and corruption control—is crucial in determining whether FDI contributes to environmental degradation or sustainability. Strong institutions enforce environmental regulations, promote clean technologies, and ensure that foreign investments comply with environmental standards. Weak institutions, on the other hand, may facilitate pollution-intensive industries through regulatory loopholes and inadequate enforcement(Hassan et al., 2022). Given Ethiopia's governance challenges, including corruption and regulatory uncertainty, it is important to examine how institutional quality moderates the environmental impact of Chinese FDI.

This study aims to address these gaps by examining the impact of Chinese FDI on CO_2 emissions in Ethiopia from 1991 to 2024. It also investigates whether stronger institutional quality mitigates the environmental impact of FDI. The study employs an autoregressive distributed lag (ARDL) bounds testing approach to explore the long-term relationship between Chinese FDI and CO_2 emissions. This research will provide valuable insights for policymakers in Ethiopia and other developing countries seeking to balance the economic benefits of FDI with the need for environmental sustainability.

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature and develops the theoretical framework. Section 3 describes the data, variables, and estimation methods. Section 4 presents the empirical results, while Section 5 discusses the findings and their policy implications. Section 6 concludes with recommendations for strengthening institutional quality and improving environmental governance in Ethiopia.

II. Literature Review and Theoretical Framework

2.1 Previous Research on FDI and Carbon Emissions

The relationship between FDI inflows and CO_2 emissions remains contested, with three principal strands in the literature. First, proponents of the PHH argue that FDI from developed to developing economies relocates pollution-intensive industries to jurisdictions with weaker environmental regulations, thereby elevating host-country emissions(Aller et al., 2021). As a result, carbon emissions in host countries increase with the expansion of FDI-led economic activities (Achuo & Ojong, 2025; Mahadevan & Sun, 2020). On the other hand, less developed countries are more inclined to adopt lax regimes to attract foreign investments to achieve economic development (Tohidi et al., 2025).Second, the Pollution Halo Hypothesis posits that FDI transfers cleaner technologies and efficiency gains, reducing emissions(Melane-Lavado et al., 2018; Wang et al., 2021). Zhu et al. (Zhu et al., 2016)also suggested that the impacts of FDI inflows on emissions are negative and become significant at higher quantiles in different countries.Third, some studies have drawn comprehensive conclusions. Using panel data from 99 countries, Shahbaz et al. (2015) claimed that the impacts of FDI inflows on carbon emissions are heterogeneous due to differences in national income(Alshubiri & Elheddad, 2020). Moreover, there is an inverted U-shaped association between FDI inflows and carbon emissions in middle-income countries. In high-income countries, however, FDI inflows can mitigate carbon emissions, while in low-income countries, the relationship is the opposite.

Beyond FDI, structural and institutional factors significantly shape CO_2 emissions.Institutional quality significantly influences carbon emissions by shaping environmental regulations and the impact of FDI. While improvements in institutional quality can boost economic activity, they may also lead to higher emissions, especially in low-income countries (Perera & Lee, 2013). Weaker environmental regulations often attract pollution-intensive industries, increasing emissions, whereas stronger regulations can limit these effects by encouraging cleaner technologies (Cole, 2007). However, better regulatory quality may also drive economic growth, initially raising emissions, but ultimately reducing them as industries adopt more sustainable practices. Porter's hypothesis suggests that strict regulations foster innovation and mitigate environmental damage (Dong et al., 2021; Herrera-Echeverri et al., 2014). Other drivers include urbanization, trade openness, and industrial value added (Li et al., 2017; Xu et al., 2022). Trade openness often positively affects emissions in developing economies via energy-intensive flows(Salman et al., 2019).Similarly, industrial value added typically contributes positively to emissions during early industrialization due to heightened energy demand(Dong et al., 2020).Economic development, for instance, is frequently linked to higher emissions in the early stages of industrialization, as countries prioritize growth over environmental protection. However, as nations reach higher income levels, they may adopt cleaner technologies, thus reducing emissions (Musah et al., 2021).In the Ethiopian context, Tolosa et al. (Ayalew, 2021) found that aggregate FDI exerts a negative and statistically significant long-run impact on CO_2 emissions, providing support for the Pollution Halo Hypothesis. In contrast, more recent evidence (Hassen et al., 2025) confirms the validity of the Pollution Haven Hypothesis in Ethiopia, demonstrating that aggregate FDI significantly intensifies CO_2 emissions. However, this latter study did not disaggregate FDI by source country—a critical limitation given China's dominance in Ethiopia's inflows, particularly in infrastructure and manufacturing—and overlooks the potential moderating role of institutional quality on the environmental effects of Chinese FDI.

2.3 Literature Gaps

Despite the growing body of research documenting the impacts of FDI inflows on carbon dioxide (CO_2) emissions, several critical gaps persist. First, findings on the environmental consequences of FDI remain inconclusive, with conflicting evidence across contexts and methodologies. Second, while direct effects have received substantial attention, far less focus has been given to moderating mechanisms through which FDI influences emissions. Third, studies on Ethiopia predominantly examine aggregate FDI rather than source-specific inflows, thereby obscuring the unique environmental characteristics of Chinese FDI, which dominates inflows and concentrates in emissions-intensive sectors such as infrastructure and manufacturing.Unlike prior research, this study addresses these gaps by investigating the impact of Chinese FDI on CO_2 emissions in Ethiopia, with a particular emphasis on the moderating role of institutional quality as a novel explanatory channel.

2.4 Theoretical Framework and Hypotheses

Despite extensive research on the environmental impacts of foreign direct investment (FDI) inflows, findings remain inconsistent, with limited attention to the underlying channels through which FDI influences carbon dioxide (CO_2) emissions. This study addresses this gap by examining the moderating role of institutional quality in the relationship between Chinese FDI and CO_2 emissions in Ethiopia, offering a nuanced explanation for source-specific environmental effects. Figure 1 illustrates the conceptual theoretical framework guiding this analysis.

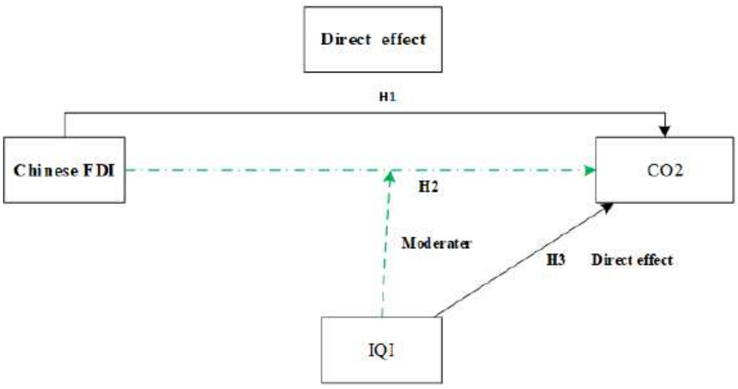

Figure 1. Conceptual Theoretical Framework.

Note: lines H1 andH3 show the direct impact of Chinese FDI and Institutional Quality (IQI) on *CO_2* emission, respectively. Lines *H2*illustrates the *moderating* effect of Institutional Quality (IQI) between Chinese FDI *and CO_2*.

Empirical evidence supports the direct positive effect of FDI on CO_2 emissions in various contexts. For instance, studies in Sub-Saharan African countries(Ali et al., 2019) and the United States (Shahbaz et al., 2019) demonstrate that FDI inflows elevate emissions, particularly in jurisdictions with weaker environmental standards. This pattern aligns with the Pollution Haven Hypothesis (PHH), which posits that pollution-intensive industries relocate to developing economies with lax regulations. Given Ethiopia's expanding industrial sector and substantial Chinese investments in infrastructure and manufacturing—often characterized by energy-intensive activities—this study posits that Chinese FDI is likely to contribute to increased emissions

Hypothesis 1 (H1). Chinese FDI inflows significantly and positively contribute to carbon emissions in Ethiopia.

Institutional quality emerges as a critical moderator. Strong institutions—encompassing effective regulation, political stability, and corruption control—can mitigate the adverse environmental impacts of FDI by enforcing standards and promoting cleaner practices (Asongu & Nwachukwu, 2016). Higher regulatory quality is negatively associated with emissions(Wawrzyniak & Doryń, 2020). In Ethiopia, governance challenges, including weak regulatory enforcement amid political and security issues, have shaped the investment landscape and potentially enabled environmental degradation(Chen et al., 2021). While FDI may drive emissions, robust institutional frameworks—through improved governance and enforcement—can attenuate these effects, potentially shifting outcomes toward the Pollution Halo Hypothesis.

Hypothesis 2 (H2): Institutional quality negatively moderates the effects of Chinese FDI inflows on carbon emissions.

III. Methodology

3.1 Data and Sources

The study utilized annual time-series data for Ethiopia from 1991 to 2024. The transition to a market-oriented economy in 1991 marked a critical turning point for Ethiopia, as it shifted from a socialist command economy to one actively engaging with global markets and encouraging foreign investment(Barber & Pilling, 2019).
Data were systematically collected from reputable international and national institutions to ensure reliability and transparency. Primary sources include the World Bank's World Development Indicators (WDI) for macroeconomic and sectoral data, International Monetary Fund (IMF) databases for financial statistics, and the Worldwide Governance Indicators (WGI) for institutional quality metrics. Disaggregated data on Chinese FDI inflows were sourced from the Ethiopian Investment Commission (EIC).
Variables were selected based on their theoretical relevance to the conceptual framework and their established use in the literature(Ali et al., 2021; Aller et al., 2021). Table 3.1 provides a comprehensive overview of all variables, including notations, descriptions, and sources.

Table 3.1: Variable Description and Sources

Variables	Notation	Description	Sources
Dependent variables			
CO_2 Emissions per capita	$lnCO_2$	log of CO_2 emissions (metric tons per capita)	WDI
Independent variable			
Chinese FDI	lnCFDI	log of net Chinese FDI inflows (million US$)	EIC
Moderating variable			
Institutional Quality index	IQI	Composite governance index from PCA on WGI	Author calc.
Interaction term	IQIxlnCFDI	The product of IQI and lnCFDI	Author calc.
Control variables			
Trade Openness	lnTOP	log of (Exports + Imports) / GDP	WDI, IMF
Real GDP per capita	lnGDP	log of GDP per capita (constant 2015 US$)	WDI, IMF
Energy Consumption	lnEC	log of energy use (kg of oil equivalent per capita)	WDI
Urbanization rate	lnURBAN	log of urban population rate (% of total population)	WDI
Industrial Value Added	lnIND_VALUE	log of Industrial Value Added (% GDP)	WDI

- **Moderate variable**

Institutional Quality Index (IQI): This is a composite measure of governance effectiveness. To avoid potential weighting biases and account for intercorrelations among these dimensions, this study applied Principal Component Analysis (PCA) to construct a single composite indicator capturing overall institutional quality, rather than relying on a single proxy.
However, to further validate the findings and determine which specific governance dimensions primarily drive the observed moderating effects, we conduct additional robustness checks using individual WGI dimensions. Among the six components of institutional quality, Regulatory Quality (RQ), Rule of Law (RL), and Control of Corruption (CC) are particularly relevant in the context of foreign direct investment (FDI) and CO_2 emissions. Thus, we re-estimate the models using these three core WGI dimensions separately: Regulatory Quality, Rule of Law, and Control of Corruption.

3.2 Model Specification

To analyze these time-series relationships, the study employs the Autoregressive Distributed Lag (ARDL) bounds testing approach to cointegration(Pesaran et al., 2001). The ARDL framework is selected for several reasons pertinent to this analysis: (1) it is applicable to variables with different orders of integration(I (0) or I (1)), a flexibility crucial for our mix of macroeconomic and social indicators; (2) it is robust and statistically efficient in studies with relatively small to moderate sample sizes, such as the current sample with T=34 annual observations; and (3) it simultaneously provides efficient estimates of both the long-run equilibrium relationship and short-run dynamic adjustments within a single, error-correcting specification, even in the presence of endogenous regressors(Nkoro & Uko, 2016).
The purpose of this study is to investigate the impacts of Chinese FDI inflows on carbon emissions in Ethiopia. Following the specifications of(Chen et al., 2021; Chen et al., 2019)and adapting the (Huang et al., 2022) moderation framework to a time-series context, the baseline model is specified as follows:

$$lnCO_{2_t} = \alpha_0 + \alpha_2 lnCFDI_t + IQI_t + \Sigma\beta_j control_t + \varepsilon_t \#EQ\ (1)$$

In addition to an investigation of the direct impacts of Chinese FDI inflows on carbon emissions, this study also further examines the moderating effect of institutional quality. Following the approaches of (Ehigiamusoe et al., 2020; Zheng et al., 2021), the moderated regression is specified as follows:

$$lnCO_{2_t} = \alpha_0 + \alpha_1 lnCFDI_t + \alpha_2 IQI_t + \alpha_3 (IQI_t * lnCFDI_t) + \Sigma\beta\_j\, control_t + \varepsilon_t \quad EQ\ (2$$

However, given the time-series nature of the data, the ARDL bounds testing approach was employed to account for dynamics and cointegration. The ARDL specification of Eq. 3 is: The general form of the unrestricted error-correction model (UECM) used for bounds testing is specified as:

$$\Delta Y_t = \alpha_0 + \beta Y_{t-1} + \gamma X_{t-1} + \sum_{i=1}^{p} \lambda_i \Delta Y_{t-i} + \sum_{i=0}^{q} \theta_j \Delta X_{t-j} + \varepsilon_t \# EQ\ (3)$$

Where, Y_t represents the dependent variables at time t, which are denoted by the equations EQ1 and EQ2. X_t is a vector of independent and control variables at time t. β and γ are the long-run coefficients, λ_i and θ_j are the coefficients of short-run dynamics,p and qare order of optimallag,and Δis the difference operator.

Upon establishing cointegration, the long-run equilibrium coefficients are derived from the normalized coefficients of the unrestricted error-correction model (UECM). For the relationship between Y_t and X_t the long-run multiplier is:

$$\pi = \frac{\gamma}{\beta}$$

Where, **β** and **γ** are coefficients on Y_{t-1} and X_{t-1} from the UECM (Equation [EQ3]**. π** represents the equilibrium effect of a one-unit change in X on Y.

Subsequently, the associated Error Correction Model (ECM) was estimated to capture short-run adjustment dynamics:

$$\Delta Y_t = \alpha_0 + \sum_{i=1}^{p} \lambda_i \Delta Y_{t-i} + \sum_{j=0}^{q} \theta_j \Delta X_{t-j} + \phi ECT_{t-1} + \varepsilon_t \# EQ\ (4)$$

where, **ECT** $_{t-1}$**,** is the one-period lagged error correction term, representing the deviation from the long-run equilibrium in the previous period. **λ** is the speed of adjustment coefficient, which measures how quickly the dependent variable returns to its long-run equilibrium after a shock. For model stability and convergence, **λ** should be negative, statistically significant, and fall between -1 and 0.

3.3. Econometric Procedures and Diagnostic Testing

The empirical analysis followed a structured sequence of econometric procedures to ensure robustness and validity. First, the stationarity properties of all variables were examined using the Augmented Dickey–Fuller (ADF) test (Dickey & Fuller, 1979), with finite-sample critical values informed by (Cheung & Lai, 1995). This step is essential to avoid spurious regressions and to confirm that no variable is integrated of order two, I (2)—a prerequisite for the ARDL bounds testing approach. Second, optimal lag length for each ARDL specification was determined using the Akaike Information Criterion (AIC) (Akaike, 2003), which performs well in finite samples (Ivanov & Kilian, 2005). The model configuration yielding the minimum AIC value was selected for each specification.

Third, the presence of long-run cointegrating relationships was tested using the ARDL bounds testing approach. The bounds test examines the joint significance of lagged level variables using an F-test, with the null hypothesis of no cointegration (H_0: β = γ = 0). Given the relatively small sample size (T = 34), the asymptotic critical values of (Pesaran et al., 2001) may be unreliable (McNown et al., 2018).Fourth, upon establishing cointegration, long-run equilibrium coefficients were derived from the normalized coefficients of the unrestricted error-correction model (UECM), and the associated Error Correction Model (ECM) was estimated to capture short-run adjustment dynamics. The error correction term (ECT) must be negative and statistically significant to confirm stable convergence towards long-run equilibrium. Fifth, model validity was assessed through diagnostic tests: serial correlation (Breusch-Godfrey LM test), heteroskedasticity (Breusch-Pagan-Godfrey test), functional form (Ramsey RESET test), and parameter stability (CUSUM and CUSUMSQ tests).

Finally, to establish causal direction, the Toda-Yamamoto (Toda & Yamamoto, 1995) modified Wald test for Granger causality was employed. This method estimates an augmented Vector Autoregression (VAR) model and is robust to the integration and cointegration properties of the variables, avoiding pre-testing biases inherent in standard Granger causality tests.

IV. Results

This chapter presents the empirical findings on the impact of T Chinese FDI inflows on carbon emissions in Ethiopia.This study also further examines the moderating effect of institutional quality (IQI). The analysis begins with pre-estimation diagnostics, followed by cointegration tests and long-run/short-run estimates from the ARDL models.

4.1 Pre-Estimation Diagnostics

4.1.1 Unit Root Tests

Stationarity was tested using the Augmented Dickey-Fuller (ADF) test with intercept and linear trend. Results are summarized in Table 4.1. lnFDI is stationary at level I (0), while all other variables are I (1) after first differencing. No variable is I (2), satisfying the ARDL bounds testing requirement.

Table 4.1. Unit Root Test Results

Variable	Level (p-value)	First Difference (p-value)	Order of Integration
$lnCO_2$	-1.893 (0.341)	-4.632 (0.001) ***	I(1)
lnCFDI	-4.512 (0.012) **	—	I(0)
IQI	-2.002 (0.285)	-5.234 (0.000) ***	I(1)
lnGDP	-1.312 (0.618)	-2.963 (0.048) **	I(1)
lnIND_VALUE	-1.893 (0.341)	-4.632 (0.001) ***	I(1)
lnEC	0.332 (0.977)	-5.262 (0.000) ***	I(1)
lnTOP	-0.954 (0.767)	-4.874 (0.000) ***	I(1)
lnURBAN	-2.245 (0.195)	-4.987 (0.000) ***	I(1)

4.1.2 Lag Length Selection and Multicollinearity Check

The optimal lag structure for each of the six ARDL specifications was determined automatically using the Akaike Information Criterion (AIC) with a maximum lag order of 4 for both the dependent and independent variables. The selected lag orders for each ARDL specification are reported below in the short-run tables.

Variance Inflation Factor (VIF) tests were conducted to assess multicollinearity. Mean VIF values were 5.12 for the baseline model and 5.16 for the interaction model, below the more liberal cutoff of 10.Detailed VIF results for each variable are presented in Appendix B. These diagnostics confirm that multicollinearity does not pose a substantial threat to the reliability or interpretation of the estimated coefficients in either model.

4.1.3 Cointegration Analysis

Table 4.2 presents the results of the ARDL bounds test for cointegration. The calculated F-statistics for both the baseline model (4.82) and the interaction model (4.68) exceed the upper-bound critical value at the 5% significance level. These results confirm the existence of a stable, long-run equilibrium relationship among the variables in both specifications.

Table 4.2. Bounds test result for cointegration

Models	Specification	F-static Values	Critical bounds at 5% lower value	Upper value	Conclusion
CO_2 :	Baseline Model	4.82	3.31	4.61	Cointegration exists
	Interaction Model	4.68	3.03	4.35	Cointegration exists

4.2 Long- Run Estimation Results for baseline and moderated models

The long-run coefficients for the CO_2 emission models are presented in Table 4.3.

In the baseline model, Chinese FDI (CFDI) exhibits a positive and statistically significant effect on CO_2 emissions. This indicates that a 1% increase in Chinese FDI is associated with a 0.057% increase in CO_2 emissions per capita in the long run, providing support for Hypothesis 1 and the Pollution Haven Hypothesis. Institutional quality (IQI) has a negative coefficient but is not statistically significant in the baseline model, suggesting that its direct effect on emissions may be weak or masked by other factors.

In the interaction model, the coefficient for lnCFDI remains positive and marginally significant ($\beta = 0.0199$). Crucially, the interaction term between IQI and lnCFDI is negative and highly significant ($\beta = -0.2384$). This provides strong support for Hypothesis 2, indicating that institutional quality negatively moderates the relationship between Chinese FDI and CO_2 emissions. The marginal effect of Chinese FDI on emissions decreases as institutional quality improves.

Control variables perform as expected. Energy consumption (lnEC) has the largest positive and highly significant effect ($\beta = 0.1553$). Industrial value added (lnIND_VALUE) also exhibits a strong positive effect ($\beta = 0.2385$), confirming that industrialization drives emissions. GDP per capita (lnGDP) is positive and significant, indicating that economic growth remains emissions-intensive. Trade openness and urbanization show positive but generally weaker effects.

Table 4.3: The long-run estimation results

Variable	Baseline Model	Interaction Model
lnCFDI	0.0571 (0.049) **	0.0199 (0.000) **
IQI	-0.0580 (0.077) *	-0.0928 (0.010) **
IQI × lnCFDI	—	-0.2384 (0.001) ***
lnGDP	0.0131 (0.094) *	0.0215 (0.273)
lnIND_VALUE	0.2385 (0.038) **	0.0862 (0.041) **
URBAN	0.0219 (0.732)	0.1433 (0.233)
lnEC	0.1553 (0.048) **	0.0342 (0.014) **
lnTOP	0.0428 (0.273)	0.0381 (0.295)
Constant	0.0432 (0.153)	0.0281 (0.083) *

4.3 Short-Run Dynamics

Table 5 presents the short-run error correction model results. The error correction term (ECT_{t-1}) is negative and highly significant in both specifications, confirming stable convergence toward long-run equilibrium following short-run shocks. The adjustment speeds are -0.498 in the baseline model and -0.513 in the interaction model, indicating that approximately 50-51% of any deviation from equilibrium is corrected within one year.

Table 4. 4: The short-run error correction model results

Variable	Baseline Model	Interaction Model
ΔlnCO_2(-1)	0.0664 (0.011) **	—
ΔlnCFDI	0.0267 (0.528)	0.0212 (0.895)
ΔlnCFDI(-1)	—	0.0342 (0.412)
ΔIQI	-0.0763 (0.019) **	-0.0466 (0.009) ***
ΔIQI (-1)	-0.0215 (0.273)	—
Δ(IQI*lnCFDI)	—	-0.0797 (0.000) ***
Δ(IQI×lnCFDI) (-1)	—	-0.0183 (0.156)
ΔlnGDP	0.0564 (0.067) *	0.0218 (0.651)
ΔlnIND_VALUE	0.0104 (0.036) **	0.0185 (0.006) ***
ΔlnIND_VALUE(-1)	0.0292 (0.795)	0.0349 (0.231)
ΔlnURBAN	0.0116 (0.032) **	0.0732 (0.409)
ΔlnURBAN (-1)	0.0215 (0.273)	—
ΔlnEC	0.0822 (0.009) **	0.0112 (0.043) **
ΔlnEC(-1)	—	0.0349 (0.231)
ΔlnTOP	0.0152 (0.418)	0.0138 (0.435)
ECT (-1)	-0.1243 (0.055) *	-0.2097 (0.020) **
R^2 (Adjusted)	0.725	0.613
F-statistic (p-value)	6.45 (0.0003)	3.62 (0.000)

*Note: *, **, *** denote significance at 10%, 5%, and 1% levels, P-values in parentheses. Variables are included based on the optimal lag structure selected by AIC: Baseline ARDL (2,0,1,0,1,1,0) and Interaction ARDL (1,1,0,0,1,0,1,1,0)*

4.3 Diagnostic and Stability Tests

To ensure the robustness and validity of the estimated ARDL models, a comprehensive set of post-estimation diagnostic and stability tests was conducted. These tests verify adherence to classical linear regression assumptions and the temporal constancy of parameters.

4.3.1 Diagnostic Tests

The models were subjected to standard post-estimation diagnostics to check for violations of key assumptions: absence of serial correlation in residuals, homoskedasticity, normality of errors, and correct functional form. The results are summarized in Table 4.7.

For two specifications (baseline and interaction models for both), the diagnostic tests fail to reject the null hypotheses at the 5% significance level. P-values exceed 0.05 across all tests, indicating no evidence of serial correlation (Breusch-Godfrey LM test), heteroskedasticity (Breusch-Pagan test), non-normal residuals (Jarque-Bera test), or specification error (Ramsey RESET test). These findings confirm that the models are statistically well-specified and reliable for inference.

Table 4.5. Diagnostic Test Results

Diagnostic Test	CO_2 Baseline Model	CO_2 Interaction Model
Autocorrelation (BG LM)	5.020 (0.064)	5.414 (0.067)
Heteroskedasticity (BP)	4.030 (0.128)	3.970 (0.137)
Normality (JB)	2.090 (0.352)	1.456 (0.497)
Ramsey RESET	0.737 (0.692)	0.634 (0.663)

Note: *Test statistics are shown with p-values in parentheses. BG LM = Breusch-Godfrey Lagrange Multiplier test; BP = Breusch-Pagan test; JB = Jarque-Bera test; RESET = Regression Equation Specification Error Test*

4.3.2 Stability Tests

Parameter stability over the sample period was assessed using recursive CUSUM (Cumulative Sum) and CUSUM of Squares (CUSUMSQ) tests. Results for all six model specifications are presented in Appendix Figures A1–A4. In every case, both CUSUM and CUSUMSQ statistics remain within the 5% critical bounds throughout the period. The stability of CUSUM indicates no progressive structural breaks in the long-run relationships, while stable CUSUMSQ statistics confirm the absence of major short-term shocks or instability in variance. This evidence strongly supports the constancy of model parameters, enhancing confidence in the estimated coefficients for policy interpretation.

4.4 Causality Analysis

Table 7 presents the results of the Toda-Yamamoto causality tests. The results reveal unidirectional causality from Chinese FDI (lnCFDI) to CO_2 emissions ($lnCO_2$), with an F-statistic of 4.12 ($p = 0.029$), supporting Hypothesis 3. There is no evidence of reverse causality from emissions to FDI ($F = 1.46$, $p = 0.249$). This directional clarity has important policy implications: efforts to mitigate environmental damage must focus on regulating FDI at source, rather than hoping that environmental improvements will somehow attract cleaner investment.

Table 4.6: Toda-Yamamoto Causality Test Results

Causality Direction	F-statistic	p-value	Conclusion
$lnCFDI \rightarrow lnCO_2$	4.12	0.029**	Causality exists
$lnCO_2 \rightarrow lnCFDI$	1.46	0.249	No causality
$lnGDP \rightarrow lnCO_2$	5.83	0.008***	Causality exists
$lnCO_2 \rightarrow lnGDP$	2.31	0.112	No causality
$lnIND\_VALUE \rightarrow lnCO_2$	6.24	0.004***	Causality exists
$lnEC \rightarrow lnCO_2$	8.57	0.000***	Causality exists
$IQI \rightarrow lnCO_2$	2.18	0.136	No causality

Note: Null hypothesis: variable in first position does not Granger-cause variable in second position. *, **, *** denote significance at 10%, 5%, and 1% levels.

Additional causality tests reveal that economic growth (lnGDP), industrial value added (lnIND_VALUE), and energy consumption (lnEC) also Granger-cause emissions, underscoring the multiple drivers of environmental degradation. Institutional quality does not directly Granger-cause emissions, consistent with its role as a moderator rather than a direct driver.

4.5 Robustness Checks: Individual Governance Dimensions

To assess which specific aspects of institutional quality drive the moderating effect observed with the composite IQI, we re-estimate the ARDL model by replacing the composite index with each of the three key Worldwide Governance Indicators (WGI) dimensions separately: Regulatory Quality (RQ), Rule of Law (RL), and Control of Corruption (CC).

The results, presented in Table 8, confirm that the moderating effects across these dimensions are consistent with the composite IQI finding.

Table4.7 Robustness Checks – Individual Governance Dimensions

Dimension	Interaction term	Coefficient (P-value)
Regulation quality	RQ*CFDI	-0.2014 (0.003) ***
Rule of law	RL*CFDI	-0.1826 (0.008) ***
Control of Corruption	CC* CFDI	-0.1632 (0.015) **

The disaggregated results closely align with the composite IQI moderation effect: across Regulatory Quality, Rule of Law, and Control of Corruption, higher institutional quality exerts a negative and statistically significant moderating influence on the Chinese FDI–CO_2 emissions nexus. These robustness checks reinforce that robust governance—particularly in regulation, legal enforcement, and anti-corruption—can substantially offset the environmental costs of Chinese FDI in Ethiopia. The findings provide further support for the notion that institutional improvements can shift FDI-related outcomes toward reduced pollution intensity (conditional mitigation of the Pollution Haven Hypothesis)

V. Discussion

5.1 Direct Effect: Evidence for the Pollution Haven Hypothesis

The positive and statistically significant long-run coefficient for Chinese FDI provides robust evidence supporting the Pollution Haven Hypothesis in the Ethiopian context. This finding indicates that Chinese investment, concentrated in manufacturing and infrastructure sectors, has contributed to increased CO_2 emissions over the study period. The result aligns with studies that have documented positive associations between FDI and emissions in developing countries (Kivyiro & Arminen, 2014; Shahbaz et al., 2015) and with qualitative evidence highlighting environmental risks associated with Chinese projects in Ethiopia (Tang et al., 2024).

However, this finding contrasts with earlier Ethiopian studies that found negative relationships between aggregate FDI and emissions(Bharadwaj, 2020). This discrepancy underscores the importance of source-specific analysis. Chinese FDI may have different environmental characteristics than FDI from other sources, reflecting its concentration in sectors with higher emissions intensity(Sivalingam et al., 2024). More recent evidence aligns with our findings, confirming the validity of the Pollution Haven Hypothesis in Ethiopia, demonstrating that aggregate FDI significantly intensifies CO_2 emissions(Hassen et al., 2025).

The relatively modest magnitude of the coefficient (0.057) suggests that while Chinese FDI contributes to emissions, its direct impact is not the dominant driver. Energy consumption ($\beta = 0.1553$) and industrial value added ($\beta = 0.2385$) have substantially larger effects, indicating that the structure of the economy and its energy system are more consequential for environmental outcomes. This aligns with findings from comprehensive sustainability research in Ethiopia(Hassen et al., 2025).

5.2 The Moderating Role of Institutional Quality

The most significant contribution of this study lies in the negative and highly significant interaction term between Chinese FDI and the composite Institutional Quality Index (IQI) ($\beta = -0.2384$). This result demonstrates that institutional quality systematically conditions—and mitigates—the environmental impact of Chinese FDI in Ethiopia. Economically, the magnitude is substantial: for each one-unit increase in the IQI (on its standardized scale), the long-run elasticity of CO_2 emissions with respect to Chinese FDI decreases by approximately 0.24 percentage points. In other words, stronger governance reduces the marginal pollution intensity of FDI inflows, effectively weakening the pollution haven dynamics observed in the baseline model.

This mitigating role operates through several complementary channels. Robust institutions enable more effective enforcement of environmental regulations, raising compliance costs for polluting activities and incentivizing the adoption of cleaner production technologies (Limazie & Woni, 2024). They also curb corruption, limiting opportunities for firms to evade environmental standards through illicit means. Moreover, stable and high-quality institutional environments foster longer-term investment horizons, encouraging foreign investors to prioritize sustainable practices and technologies with extended payback periods rather than short-term, high-pollution strategies (Sokolova & Tretyakova, 2025).

These findings align closely with prior researchJinapor et al., 2024, similarly demonstrate that institutional quality plays a crucial moderating role in offsetting the adverse environmental effects of FDI and industrialization across sub-Saharan Africa, promoting overall environmental sustainability. In the Ethiopian context, studies employing principal component analysis to construct composite governance indices have shown that governance quality significantly shapes sustainability outcomes, including environmental dimensions (Hassen et al., 2025). The consistency across the disaggregated Worldwide Governance Indicators—particularly Regulatory Quality, Rule of Law, and Control of Corruption, all negative and significant—further reinforces this conclusion: improvements in core governance pillars (regulation, legal enforcement, and anti-corruption) are key mechanisms for attenuating FDI-induced emissions.

In Ethiopia, this insight is especially pertinent amid documented governance challenges, including institutional weaknesses, regulatory gaps, and security-related constraints that have historically complicated effective oversight of foreign investments (Ashine, 2024). The results suggest that targeted institutional reforms—such as strengthening environmental regulatory frameworks, enhancing rule of law, and intensifying anti-corruption measures—could substantially offset the ecological costs of FDI-led growth and help transition toward more sustainable investment patterns.

Complementing these moderation insights, the Toda-Yamamoto causality tests provide clear directional evidence: Chinese FDI Granger-causes CO_2 emissions (unidirectional, with no reverse causality). This confirms FDI as a primary driver of environmental degradation rather than a response to pre-existing environmental conditions. Consequently, policy efforts to curb the environmental footprint of FDI should prioritize upstream regulation of incoming investments (e.g., sector-specific environmental standards, technology transfer requirements, and governance-linked incentives) rather than relying solely on downstream environmental improvements to attract cleaner FDI.

Overall, while Chinese FDI contributes to emissions in line with the Pollution Haven Hypothesis, the conditional moderating role of institutional quality offers a pathway to mitigation. Strengthening governance not only reduces pollution risks but also enhances the potential for FDI to support greener, more sustainable development in Ethiopia.

VI. Conclusion and Policy Implications

6.1 Summary of Findings

This study provides novel evidence on the environmental footprint of Chinese FDI in Ethiopia (1991–2024), using ARDL bounds testing and Toda-Yamamoto causality analysis. Key results confirm a positive long-run effect of Chinese FDI on CO_2 emissions, supporting the Pollution Haven Hypothesis amid Ethiopia's emissions-intensive industrialization. Institutional quality exerts a substantial negative moderating effect, demonstrating that stronger governance—via regulatory enforcement and corruption control—significantly attenuates this impact. Unidirectional causality from Chinese FDI to emissions underscores FDI as a driver rather than a response, while controls (notably energy consumption and industrial value added) dominate emissions dynamics. These findings highlight a conditional PHH dynamic: Chinese investment contributes to degradation, but this is not inevitable and can be mitigated through institutional reforms.

6.2 Policy Recommendations

The findings carry clear and actionable implications for Ethiopian policymakers seeking to balance FDI-driven growth with environmental sustainability.

First, Ethiopia should prioritize strengthening environmental regulatory frameworks and institutional capacity. This includes bolstering the Environmental Protection Authority (EPA) with adequate resources, technical expertise, and authority to develop and enforce sector-specific environmental standards, particularly for high-impact industries attracting Chinese investment.Second, greater transparency and stakeholder participation should be institutionalized through mandatory, rigorous environmental impact assessments (EIAs), public disclosure of EIA outcomes, and accessible grievance redress mechanisms for affected communities.

Third, investment promotion and approval processes—led by the Ethiopian Investment Commission—must integrate environmental criteria into screening, prioritization, and incentive structures. This could redirect Chinese FDI inflows toward cleaner sectors, such as renewable energy, green manufacturing, and sustainable agriculture, while discouraging pollution-intensive activities.Fourth, to maximize developmental co-benefits, policies should actively promote technology transfer and green partnerships. This can be achieved through joint-venture requirements, local content rules favoring environmentally friendly technologies, and incentives for cleaner production practices.

Finally, enhanced inter-agency coordination among the Ethiopian Investment Commission, EPA, Ministry of Industry, Ministry of Finance, and regional authorities is essential to ensure coherent implementation. Progressive alignment with international best practices—such as the Equator Principles, IFC Performance Standards, and relevant Chinese green finance guidelines—would further strengthen governance and signal Ethiopia's commitment to sustainable FDI-led development.

6.3 Limitations and Future Research

Several limitations should be acknowledged to contextualize the findings and guide future extensions.First, the analysis relies on aggregate national-level data, which may obscure sectoral and regional heterogeneity in Chinese FDI-environment linkages (e.g., manufacturing vs. agriculture or urban vs. rural impacts in Ethiopia).

Second, the focus on CO_2 emissions as the primary proxy for environmental degradation, while standard in the literature, excludes other important dimensions such as water pollution, soil degradation, biodiversity loss, deforestation, or local air quality effects—particularly salient in Ethiopia's resource-dependent and agrarian economy.

Future research could address these gaps by utilizing project-level or firm-level data on Chinese investments, conducting qualitative case studies of specific sectors or regions, comparing the environmental footprint of Chinese FDI with that from other source countries, and extending the analysis to a broader set of environmental indicators. Longitudinal assessments of post-reform outcomes following targeted institutional improvements would also provide valuable insights into causal pathways.

Despite these constraints, this research advances understanding of source-specific FDI-environment linkages in low-income settings, affirming that institutional quality critically shapes whether Chinese FDI exacerbates or alleviates ecological pressures in Ethiopia.

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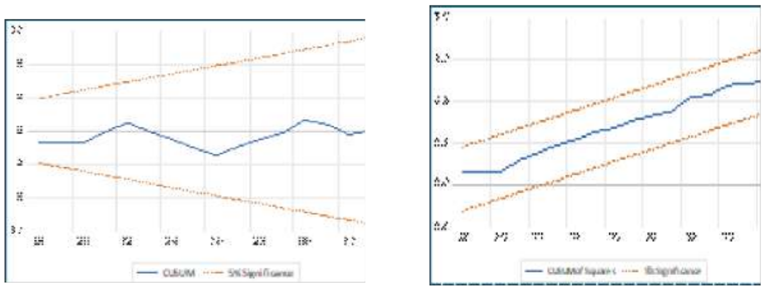
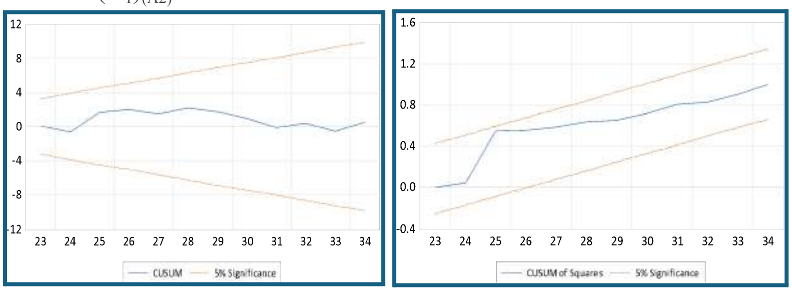
Appendix A



(A_1)(A2)



(A_3) (A4)

Figure A: (A1) CUSUM test for baseline CO_2model, (A2) CUSUMQ test for baseline CO_2 model, (A3) CUSUM test for moderated CO_2 model, (A4) CUSUMQ test for moderated CO2 model

Appendix B

Table 4.7. Multicollinearity Diagnostics result for CO2 Emission

Baseline Model: CO2 Emission

Variable	VIF	1/VIF
lnURBAN	7.97	0.125520
lnGDP	6.68	0.149619
lnCFDI	5.60	0.178629
lnEC	4.50	0.222108
IQI	4.19	0.238552
lnIndu-Value	1.77	0.563781
Mean VIF	5.12	

Interaction Model: CO2 Emission

Variable	VIF	1/VIF
lnURBAN	8.06	0.124031
lnGDP	7.24	0.138136
IQI*lnCFDI	5.91	0.169172
lnCFDI	4.51	0.221526
lnEC	4.42	0.226050
IQI	3.45	0.289855
lnIndu-value	2.54	0.393701
Mean VIF	5.16	