Asymmetric effects of Trade Openness, Foreign Direct Investment and Climate Change in Philippines' Manufacturing Industry: Evidence from a non-linear

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Abstract:

This study examines asymmetric short-run and long-run effects of trade openness and foreign direct investment (FDI) on environmental degradation in the Philippine manufacturing sector using annual time series data spanning 1986–2023. Carbon dioxide (CO_2) emissions are employed as the dependent variable to capture environmental quality. To account for potential nonlinearities and asymmetric adjustments, the study adopts the nonlinear autoregressive distributed lag (NARDL) framework. The results confirm the existence of asymmetric cointegration among CO_2 emissions, trade openness, FDI, manufacturing activity, and economic growth. In the short run, positive shocks to trade openness and FDI increase CO_2 emissions, while negative shocks exert stronger contractionary effects on emissions. In the long run, negative shocks to trade openness significantly reduce CO_2 emissions, whereas positive shocks are statistically insignificant, indicating asymmetric environmental responses to trade expansion and contraction. Similarly, contractionary shocks to FDI reduce emissions more strongly than expansionary

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shocks increase them. These findings highlight that the environmental effects of trade openness and FDI are nonlinear and asymmetric, validating the use of the NARDL approach. The study highlights the importance of environmentally conditioned trade and investment policies, green technology-oriented FDI, and strengthened environmental regulations within the manufacturing sector.

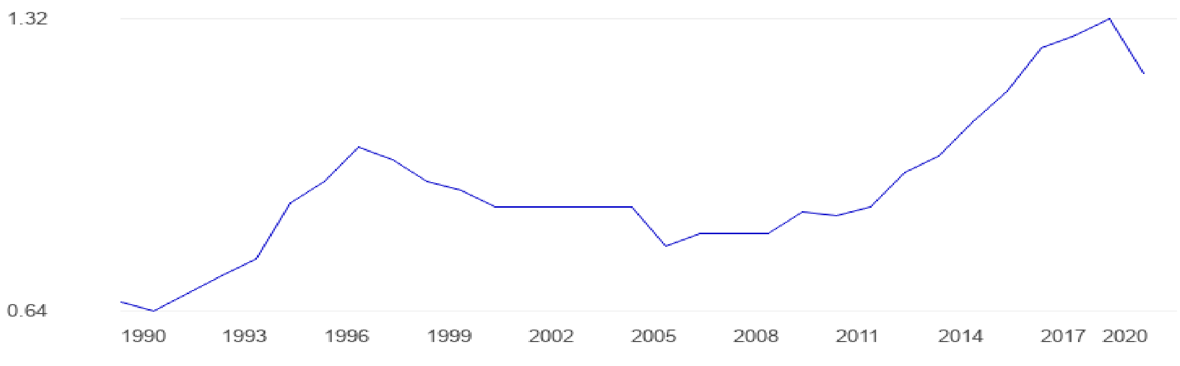
Keywords :CO_2 emissions; Trade openness; foreign direct investment; Manufacturing sector; NARDL; Asymmetry.

I- Introduction:

Climate change and global warming have become a leading issue of concern in recent times, due to their impact on human activities and the environment since the International Climate Conference in Copenhagen in 2009. The conference raised the attention of the world on the associated effects of global warming and its relationship with gaseous emissions. Parts of the consequences of that conference and its prototype global meetings on the environment, like that of Kyoto and brazil which was held a year earlier, stressed the need for stabilizing world energy consumption and reduction in carbon emission.

Combustion of fossil fuels such as coal, oil, and natural gas in the production of fuels for transport and other industrial uses, which was established many years ago, attracts significant global concern as it releases greenhouse gases (GHG), particularly carbon dioxide (CO_2) into the atmosphere (Cannaon and Sperling 20019). Between 1991 and 2019, the Philippines' average value was 0.92 metric tons, with minimum values of 0.64 metric tons and maximum values of 1.32 metric tons. The most recent figure is 1.19 metric tons, from 2020

Fig 1: Trends in Foreign Direct Investment, Trade Openness, and Climate-Relevant Energy Shifts



Source: The Global Economy (2026)

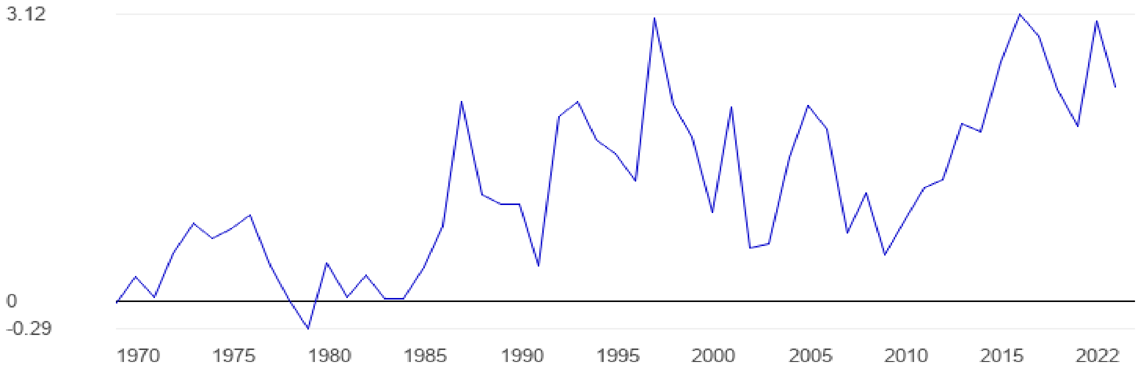
As shown in figure 1 above, the increase in the demand for clean energy, falling fuel reserves, and the potentials towards reducing dependence on crude oil have important effects on international policy and economy, and at the same time make biomass fuel a more apt substitute for fossil fuels (Demirbas, 2008).

Since the 1980s, developing countries have started to open their economy to integrate with other countries of the world. The superiority of developed nations, coupled with emerging multinational companies in the 1960s, played a vital role in the world trade openings. Globalization also became popular in the 1990s and helped to boost world economic integration, where it became possible for people to invest anywhere in the world.

Developing economies as the host countries more often experience changes in inflow of Foreign Direct Investment, in fact it’s seen as engine to their economic growth as it provides capital for investment, employment opportunities and foreign exchange advantages, (Mohammed & Hayewa 2018).

The controversial relationship between trade openness, foreign direct investments, and climate change has been the topic of an impressive body of literature, international debates, and strategic agreements. Open economies paved the way for the import of new technologies and ideas from the rest of the world, which has led to a better division of labour, new methods of production, and new products by enjoying comparative advantages. FDI flow has increased during the last two decades in almost every nation of the world, including the Philippines. Foreign ownership of production facilities is reflected in foreign direct investment in the Philippines and other nations. The percentage of foreign ownership must equal at least 10% of the company's worth for it to be categorized as foreign direct investment. The investment may go into services, manufacturing, farming, or other industries.

Fig 2: Foreign Direct Investment and Its Impact on Energy Consumption and Carbon Emissions in the Philippines

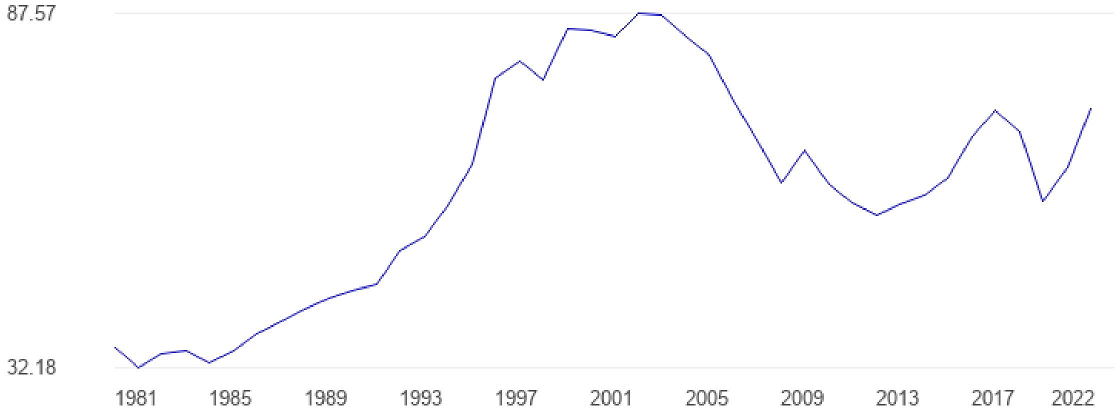


Source: The Global Economy (2026)

As illustrated in figure 2, FDI and its activities in the Philippines have been associated with increased energy consumption and carbon dioxide emissions. The increasing threat of greenhouse gases and global warming, along with climate change, has called for more attention and discussion on the danger of its consequences on the natural environment.

Data for the Philippines from 1981 to 2022 are provided for such an indicator. The Philippines had an average percentage of 60.25 percent during that time, with minimum values of 32.18 percent in 1982 and maximum values of 87.57 percent in 2003. 72.44 percent is the most recent figure from 2022. In contrast, based on 157 countries, the global average in 2022 is 100.30 percent.

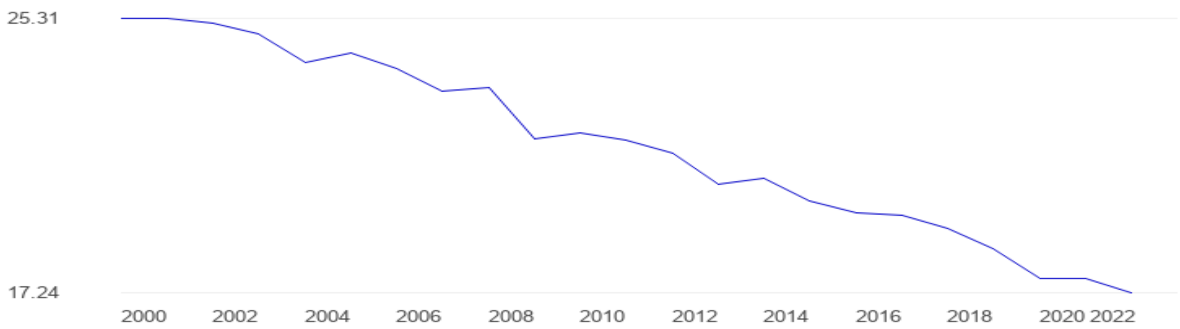
Fig 3: Trade Openness and Sustainable Development Indicators in the Philippines



Source: The Global Economy (2026)

As shown in Figure 3**,** trade openness in the Philippines has fluctuated over the period 2001–2022, with an average of 21.56%. The minimum value of 17.24% occurred in 2022, while the maximum of 25.31% was recorded in 2001. These trends illustrate the country's engagement in international trade and its potential implications for sustainable development, as highlighted by the World Bank and the WTO

Fig 4: The Impact of Trade Openness and Foreign Direct Investment on Carbon Emissions in the Philippines



Source: The Global Economy (2026)

Figure 4 illustrates the relationship between trade openness, foreign direct investment, and carbon emissions in the Philippines. This figure highlights the country-level dynamics of how international economic activities contribute to environmental outcomes, emphasizing the long-run interactions between FDI inflows, trade liberalization, and climate change.

Indeed, several previous studies have focused on the influence of macroeconomic factors on aggregate measures of economic growth rather than conducting country-level analyses, which this study aims to address. This research is designed to examine the impact of trade openness and foreign direct investment on climate change in the Philippines. In particular, it seeks to determine the long-run relationship between foreign direct investment and carbon emissions in the country, providing insights into how international economic activities contribute to environmental outcomes at the national level.

1. The theoretical framework of the study. (Times New Roman, size 12**)**

Southeast Asia's persistent efforts to industrialize and catch up to the developed world are partly to blame for the subregion's rising emissions of greenhouse gases, particularly carbon dioxide.

Much like Southeast Asia, in a similar stance, Yao and Ameyaw (2018) state that other similar countries in West Africa view as a non-issue, have horrible impacts on the ecosystem, endangering the sustainability of the future. Environmental protection laws, rules, and initiatives need to be implemented quickly in order to support financial development (FDI influx) and economic growth. Zugravu-Soilita (2017) asserts that the actions of multinational corporations (MNCs) through foreign direct investment (FDI) are primarily responsible for the rise in greenhouse gas and other pollutant emissions that contribute to climate change. In particular, nations possessing abundant natural resources and lacking strict environmental rules frequently witness a rise in carbon dioxide emissions due to foreign direct investment. This makes the claim that between 2000 and 2030, emissions of greenhouse gases and other ozone-depleting gases could increase from 25% to 90%, posing a serious threat to national health due to the simultaneous consequences of climate change (Sarkodie, 2018).

According to studies by Fankhauser and McDermott (2014), poor nations, particularly those in Africa, are more vulnerable to the consequences of climate change than developed industrial nations are to the current environmental issues. The information sheet distributed following the 2002 United Nations Climate Change Conference in Nairobi noted that between 1990 and 2000, temperatures in Africa rose by about 0.7°C, which resulted in decreased food production, droughts, floods, and a loss of biodiversity.

1.1. Definition of study variables. (Times New Roman, size 12**)**

Dataset and Sources

Table 1 below describes the data used in this study. The data is a set of yearly data for the years 1986–2023. The selection period is mostly explained by the data's accessibility. Prior to being estimated, all variables are transformed into natural logarithms. Although the sample consists of 37 annual observations, the NARDL framework remains appropriate as it was specifically developed for small-sample time-series analysis (Shin et al., 2014). Unlike conventional nonlinear models, NARDL allows for mixed orders of integration and yields reliable estimates in samples below 50 observations. This approach has been widely applied in recent environmental and macroeconomic studies with comparable sample sizes.

Tab 1. Data Variable Measurement

S/N.	Variable	Code	Definition	Source

1.	Carbon dioxide emission	$lCO_{2,t}$	Is the proxy for the environmental quality variable, measured by CO2 emission per capita (CO2) in metric tons?	WDI
3.	Trade openness	$ltop_t$	The proportion of GDP that banks lend domestically to the private sector.	WDI
4.	Foreign direct investment	$lfdi_t$	Represents foreign direct investment as a percentage of GDP.	WDI
5.	Manufacturing sector	$lman_t$	Manufacturing sector added value % of GDP	WDI
6.	GDP	$lgdp_t$	Growth of the economy	WDI

Notes: WDI is an acronym for World Development Indicators. It is also worth noting that we interpolated for missing observations in $lfdi$, using Chow and Lin (1971) method.

Source: World Development Indicators (2024).

2. The experimental framework for the study. (Times New Roman, size 12**)**

In the research on the environmental effects of foreign direct investment, the structural equation linking environmental contamination to its origins is frequently cited (Stern 2004). In this study, the CO2-FDI regression model is employed. We create a model with GDP, trade openness, and foreign direct investment as the regressors and C02 as the dependent variable in accordance with the aim of this study.

$$CO2_t = f(ltop_t, lfdi_t, lman_t, lgdp_t) \ldots\ldots \quad (1)$$

The econometrics approach utilized in this paper followed three stages: First, in addition to the standard ADF, PP, and KPSS tests, Guris (2018)'s nonlinear Fourier based unit root test is used to evaluate the stationarity status of the variables The traditional tests verify that none of the variables are I(2) by looking at the order of integration, whereas the latter will test the nonlinear stationarity of the variables. Second, we examined the asymmetric long- and short-term effects of the regressors on C02 using the NARDL approach. Lastly, we subjected the model to a few crucial diagnostic tests.

While the Chow-Lin interpolation method was employed to address limited missing observations, its use is acknowledged as a potential source of bias. To mitigate this concern, multiple unit root tests, including nonlinear Fourier-based tests, were conducted, and the consistency of the integration order across methods supports the robustness of the results.

Non-Linear Autoregressive Distributed Lag Model

Macroeconomic factors are nonlinear, according to recent research. This implies that the framework of dismantled explanatory variables can be used for modeling co-integration, or asymmetric co-integration. It is used to determine whether positive shocks from the independent variables have an equal impact on the dependent variables as do their negative shocks. As mentioned by Shin et al. (2014), the two-step Engle-Granger technique of asymmetric co-integration is the most widely used strategy, despite the fact that there are other ways to describe asymmetric interactions (Schorderet, 2003; Escribano et al., 2006). The single-step ECM estimation of Shin et al. (2014), which models the long- and short-term asymmetries known as NARDL concurrently, is more efficient than the two-step Engle-Granger technique of asymmetric cointegration, notwithstanding the latter's effectiveness for short-term modeling.

NARDL is an expansion of the framework developed by Shin et al. (2001) and satisfies the requirements to be utilized with ARDL time series applications. The first is that I(2) variables shouldn't be included due to the stationary character of the variables. In light of this, we performed a unit root test on the variables using the conventional methods of Augmented Dicky Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS). Next, we wrote (eq. 1) in accordance with Shin, Yu, and Greenwood-Nimmo (2014).

$$\begin{aligned}\Delta lC02_t = {} & \beta_0 + \sum_{i=0}^{m} \beta_1 \Delta lC02_{t-i} + \sum_{i=0}^{m} \beta_2 \Delta ltop_{t-i}^{+} + \sum_{i=0}^{m} \beta_3 \Delta ltop_{t-i}^{-} + \sum_{i=0}^{m} \beta_4 \Delta lfdi_{t-i}^{+} \\ & + \sum_{i=0}^{m} \beta_5 \Delta lfdi_{t-i}^{-} + \sum_{i=0}^{m} \beta_6 \Delta lman_{t-i}^{+} + \sum_{i=0}^{m} \beta_7 \Delta lman_{t-i}^{-} + \sum_{i=0}^{m} \beta_8 \Delta lgdp_{t-i}^{+} \\ & + \sum_{i=0}^{m} \beta_9 \Delta lgdp_{t-i}^{-} + \gamma_1 C02_{t-1} + \gamma_2\, ltop_{t-1}^{+} + \gamma_3 \Delta ltop_{t-1}^{-} + \gamma_4\, lfdi_{t-1}^{+} \\ & + \gamma_5\, lfdi_{t-1}^{-} + \gamma_6\, lman_{t-1}^{+} + \gamma_7\, lmn_{t-1}^{-} + \gamma_8\, lgdp_{t-1}^{+} + \gamma_9\, lgdp_{t-1}^{-} + \psi_t DU_t \\ & + \epsilon_t \qquad (2)\end{aligned}$$

The first difference of the variable is indicated by the difference operator Δ. The lagged values are represented by i, the short-run and long-run coefficients are represented by β_1 to γ_9 and φ_1 to γ_9, respectively, and the disturbance term is represented by ∈_t.

The previously developed NARDL error correcting equation is as follows:

$$\Delta lC02_t = \beta_0 + \sum_{i=0}^{m} \beta_1 \Delta lC02_{t-i} + \sum_{i=0}^{m} \beta_2 \Delta ltop_{t-i}^{+} + \sum_{i=0}^{m} \beta_3 \Delta ltop_{t-i}^{-} + \sum_{i=0}^{m} \beta_4 \Delta lfdi_{t-i}^{+} + \sum_{i=0}^{m} \beta_5 \Delta lfdi_{t-i}^{-} + \sum_{i=0}^{m} \beta_6 \Delta lman_{t-i}^{+} + \sum_{i=0}^{m} \beta_7 \Delta lman_{t-i}^{-} + \sum_{i=0}^{m} \beta_8 \Delta lgdp_{t-i}^{+} + \sum_{i=0}^{m} \beta_9 \Delta lgdp_{t-i}^{-} + \vartheta_t ect_{t-1} + \epsilon_t \quad (3)$$

3. Result Interpretation and Discussion

Together with pairwise correlations between the variables, Table 2 offers a concise synopsis of the key features of the observations of the yearly time series data that we used for the study. The findings demonstrate a strong and positive correlation between the dependent variable, LC02, and the four independent variables, LOP, LFDI, LMAN, and LGDP. The pairwise correlations' findings range from 0.65 to 0.95.

Tab 2: Descriptive Statistics and Pair-wise Correlations

	LCO2	LTOP	LFDI	LMAN	LGDP
Mean	11.3408	7.5892	2.1544	6.2236	10.3482
Std. Dev.	0.2361	0.0578	0.3423	3.1507	0.53524
Min.	11.6558	6.5201	1.5889	1.6093	9.7934
Max.	10.8101	6.7030	2.9767	11.5607	10.1857
JB	0.9391	3.2514	1.7547	3.9067	4.1976
Probability	0.5242	0.1967	0.4189	0.1516	0.1235
Observations	37	37	37	37	37
$LC0_2$	1.0000				
LTOP	0.9661	1.0000			
LFDI	0.6409	0.7210	1.0000		
LMAN	0.7427	0.9102	0.8403	1.0000	
LGDP	0.8496	0.9458	0.8289	0.9481	1.0000

Source: Researchers’ computation using EViews 10 (2026)

Unit Root Test

The primary features of the annual time series data observations that we used for the study are briefly summarized in Table 2, along with pairwise correlations between the variables. A significant and positive association exists between the dependent variable, LC02, and the four independent variables, LOP, LFDI, LMAN, and LGDP, according to the findings. The pairwise correlation's results fall between 0.65 and 0.95.

Tab 3: Stationarity test results

Variables	ADF		PP		KPSS	
	Level	1st difference	level	1st difference	level	1st difference
$LC0_2$	-1.6167	-9.7173**	-1.1779	-15.246**	0.7311*	
LTOP	-0.4665	-5.8336**	0.22810	-6.9620**	0.7345	0.3358**
LFDI	-1.7333	-5.8010**	-1.5843	-9.9777**	0.6549	0.5001*
LMAN	-0.4814	-4.7594**	-0.5012	-4.7798**	0.7523	0.1421**
LGDP	-1.0410	-3.7930**	0.4511	-3.7832**	0.7448	0.292893**

Source: Researchers' computation using EViews 10 (2026)

However, Güriş (2018) pointed out that while typical unit root tests often do not demonstrate any stationarity when addressing nonlinear variables, testing for order of integration in nonlinear models is insufficient. To get around this issue, Güriş (2018) proposed a brand-new flexible Fourier form nonlinear unit root test. To determine whether the variables are nonlinear stationary, the nonlinear adjustment is simulated using an exponential smooth threshold autoregressive (ESTAR) model.

Tab 4: Guris (2018) Nonlinear Unit Root Test

Variables	Lags	Test statistics	Decision	Critical values K=1	
$LC0_2$	2	17.22687**	Stationary	1%	20.31
LTOP	2	15.97637**	Stationary	5%	13.72
LFDI	2	6.293270	Nonlinear unit root	10%	11.42
LMAN	2	13.88877*	Stationary		
LGDP	2	17.42102**	Stationary		

Note: the signs of ***, **, and * refer to the rejection of the unit root hypothesis at 1%, 5%, and 10% level, respectively. lag method (AIC), Maximum lags (3).

Source: Researchers' computation using EViews 10 (2026)

Guris's (2018) nonlinear unit root test indicates that all other variables are stable and demonstrate nonlinearity with breaks at unknown dates at a significance level of 5%, except for the manufacturing sector, which displays a unit root.

Short and Long-run NARDL Results

The study conducted both short- and long-term NARDL estimations to look into the effects of economic growth, trade openness, foreign direct investment, and CO2 emissions in the Philippines. The unit test results displayed in Tables 3 and 4 validated that NARDL was applicable.

Tab 5: Short and long-run NARDL Results

NARDL Short-Run Result; Dependent Variable: $LC0_2$						
Regressors	Lags					
	0	1				
Δ $LTOP^+$	0.225846 (0.2041)	0.435727 (0.0966)***				
Δ $LFDI^+$	0.055626 (0.0260) **	-1.247151 (0.0018)*				
Δ $LMAN^-$	-0.061575 (0.5217)	-0.629001 (0.0418)**				
Δ $LGDP^+$	0.193647 (0.8508)	-2.245438 (0.0048)*				
NARDL Long-Run Result						
$LTOP^+$	$LTOP^-$	$LFDI^+$	$LFDI^-$	$LMAN^-$	$LGDP^+$	$LGDP^-$
-0.2905 (0.0010) *	-0.2138 (0.7696)	-0.3177 (0.3055)	2.0970 (0.0757) ***	-0.3856 (0.0673) ***	7.4869 (0.1124)	9.6556 (0.0967) ***
Diagnostics						
Bound test	ECM_{t-1}	Adj. R^2	Hetero. Test	LM Test		

4.152410	-0.863618	0.739170	(0.1280)	(0.1277)
	(0.0000) *			
$LTOP_{LR}$	$LFDI_{LR}$	$LMAN_{LR}$	LGD_{LR}	
25.18963	14.77864	17.56625	5.79223	
(0.0000)	(0.0006)	(0.0002)	(0.0161)	

() = Probability values, LR=Long-run Wald test. *, **, *** mean significance at 1%, 5% and 10% respectively

Source: Researchers' computation using EViews 10 (2026)

Table 5 displays the estimation results of equation (2). According to the short-term conclusion, there will be a 0.40% increase in emissions in the current short-term period for every 1% increase in LTOP from the previous year; however, the positive shock of LTOP in the current time is statistically small. Stated differently, the current foreign direct investment might have a positive effect on emission levels, but it won't be apparent for another year. Table 5 displays the estimation results of equation (2). According to the short-term conclusion, there will be a 0.40% increase in emissions in the current short-term period for every 1% increase in LTOP from the previous year; however, the positive shock of LTOP in the current time is statistically small. Stated differently, the credit given to the private sector during this current period might have a positive effect on emission levels, but it won't be apparent for another year. A shock to LTOP+ will result in a 0.21 reduction in emissions overall. Even if this was not expected in advance, the results may indicate that consumers and companies are utilizing more renewable energy- or environmentally-friendly-powered items in the industrial sector. This outcome aligns with studies conducted in the economies of West Africa (Bediako et al., 2022; Mordi et al., 2022). It is demonstrated that a positive shock to foreign direct investment reduces emissions by 2.09, not the expected beneficial effect on emissions. This is the case because a decline in foreign direct investment leads to a contraction in the manufacturing sector, which lowers production capacity within the industry. Reductions in output would undoubtedly result in lower CO_2 emissions; this was anticipated beforehand.

CO_2 increases and decreases by 0.38 and 0.81, respectively, in response to positive and negative shocks to the industrial sector. Finally, a decrease in GDP due to the effects of human output results in a 9.65% decrease in CO_2 emissions. The nonlinear asymmetries in our model are frequently validated by the long-run Wald test of the regressors. Furthermore, except for LMAN, our dynamic multiplier graphs (figures 3-5) demonstrate that the dependent variable reacts more to negative than to positive shocks from the regressors.

Most people agree that trade openness is to blame for the Philippines' declining carbon dioxide emissions. This conclusion is not unique because it is consistent with reports by Bediako et al. (2022) and Mordi et al. (2022), respectively. The different approaches taken could be related to this in some way. In the aforementioned study, an estimate was conducted under the assumption of a symmetrical relationship; nevertheless, in our instance, we thought that the regressors' positive and negative effects on C02 were highly asymmetric. This notion is supported by the dynamic multipliers graphs that follow, which show that C02 reacts more to negative shocks than to positive ones.

The post-estimation findings show that: the bound test confirms the variables' cointegration and shows that a sustained relationship exists between them; The ECM reverses any shock that induces disequilibrium at a rate of 86% per second and is statistically significant, negative, and less than unity. The revised R2 of 0.73 indicates that the model is fit. The model's residual errors are homoscedastic, and there is no serial correlation, according to the Heteroskedasticity test and the Breusch-Godfrey serial correlation (LM Test) probability values of (0.1280) and (0.1277). The model's parameter stability is shown by the CUSUM and CUSUM squares tests.

Tab 6: NARDL Results

NARDL Long-Run Result				
Dependent Variable: $LC0_2$				
TOP^+	TOP^-	LFDI	LGDP	
-0.0340	-0.1621	2.7916	-0.3266	
(0.3939)	(0.0007) *	(0.0469) **	(0.3785)	
Diagnostics				
Bound test	ECM_{t-1}	Adj. R^2	Heteroskedasticity test	LM Test
2.5837	-0.9179	0.5757	(0.8095)	(0.5445)
	(0.0000) *			

( ) = Probability values, * means significance at 1%.

Source: Researchers' computation using EViews 10 (2026)

A negative TOP shock will cause an increase in LC02 emission of 0.16, whereas a positive shock is not statistically significant. Even though a unit increase in FDI (LFDI) will result in an increase in emission of 0.04, the data demonstrate that LFDI and LGDP have no long-term asymmetric effect on LC02. This makes sense, considering that TOP influences LC02 through LFDI.

Limitation of the Study

A limitation of this study is the exclusion of energy consumption and energy mix variables, which are known determinants of CO_2 emissions. This omission is driven by data constraints over the study period. Future research may extend the present framework by incorporating renewable and non-renewable energy indicators to further refine the trade environment nexus.

After presenting the results reached, they must be discussed by giving them their place in their field and comparing them with previous studies, showing their extent and opposition to previous results.

Conclusion

This study investigates the asymmetric relationship between trade openness, foreign direct investment, and carbon dioxide emissions in the Philippine manufacturing sector within a nonlinear ARDL framework. Unlike most existing studies that assume linear and symmetric relationships, this research explicitly models asymmetries in both the short and long run. The empirical results provide strong evidence of asymmetric cointegration among the variables, indicating that positive and negative shocks to trade openness and FDI exert unequal effects on environmental degradation.

The findings reveal that, in the short run, increases in trade openness and FDI tend to raise CO_2 emissions, reflecting scale effects associated with expanded manufacturing activity and increased energy demand. However, negative shocks to these variables lead to proportionally larger reductions in emissions, suggesting that environmental responses are more sensitive to contractions than expansions. In the long run, negative shocks to trade openness significantly reduce CO_2 emissions, while positive shocks do not exert a statistically significant effect. This implies that environmental improvements occur more strongly during periods of reduced trade intensity than during trade expansion phases.

Similarly, contractionary shocks to FDI are associated with notable reductions in emissions, whereas expansionary shocks do not generate equivalent increases.

These results support the coexistence of pollution-haven and pollution-halo mechanisms, depending on the direction of trade and investment shocks. The asymmetric nature of the findings indicates that linear models may obscure critical dynamics in the trade–environment nexus. Overall, the study demonstrates that the environmental impact of trade openness and FDI in the Philippine manufacturing sector is fundamentally nonlinear, underscoring the necessity of asymmetric modeling approaches in environmental economics.

Policy Implications and Recommendations

The policy implications of this study are derived strictly from the estimated NARDL results and the variables included in the empirical model. Given the asymmetric effects of trade openness and foreign direct investment on CO_2 emissions, policymakers should recognize that trade and investment expansion do not automatically translate into environmental improvement. Instead, environmental outcomes depend on the nature and quality of trade and investment flows.

First, trade liberalization policies should be accompanied by strong environmental safeguards within the manufacturing sector. Since positive shocks to trade openness tend to increase emissions in the short run, environmental standards must be enforced to prevent environmentally harmful production practices during periods of trade expansion. Environmental clauses in trade agreements and stricter compliance monitoring can help mitigate adverse environmental effects.

Second, foreign direct investment policies should prioritize environmentally sustainable and technology-intensive investments. The finding that negative shocks to FDI significantly reduce emissions suggests that environmentally harmful investment activities play a role in driving pollution. Therefore, investment screening mechanisms should favor green technologies, energy-efficient manufacturing processes, and low-carbon production methods. Incentives such as tax credits or subsidies for environmentally friendly foreign investments may enhance the pollution-reducing potential of FDI.

Third, the government should strengthen environmental regulations targeting the manufacturing sector, particularly through pollution taxes, emissions standards, and enforcement of environmental compliance. Given the asymmetric sensitivity of CO_2 emissions to economic shocks, regulatory measures can play a stabilizing role in limiting emission increases during periods of economic and trade expansion.

Finally, future environmental and trade policies should be designed with an explicit recognition of nonlinear and asymmetric dynamics. Ignoring these asymmetries may lead to ineffective or counterproductive policy outcomes. Incorporating asymmetric responses into policy design will improve the effectiveness of sustainable trade and investment strategies in the Philippines.

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