Araştırma Makalesi / Research Article

Does Financial Development Asymmetrically Affect CO_2 Emissions in Türkiye? A NARDL Approach

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Abstract

This study examines the asymmetric effects of financial development, economic growth, trade openness, and inflation on CO2 emissions in Türkiye over the period 1976-2024 using a nonlinear autoregressive distributed lag (NARDL) approach. The results of the bounds test provide evidence of a cointegrating relationship among the variables. The empirical results demonstrate that, in the long term, negative shocks to financial development lead to a significant increase in CO_2 emissions, whereas positive shocks have no statistically significant effect. Similarly, in the long term, trade expansion increases emissions, while contractions in trade volume do not reduce them; short-run trade impacts, however, remain symmetric. This finding suggests that credit contractions adversely affect environmental quality. Positive inflation shocks temporarily raise CO2 emissions in the short run but reduce them in the long run through the contraction of aggregate demand. Overall, the results point to the need for nonlinear policy frameworks in Türkiye that account for financial stability.

Keywords: *CO_2 Emissions, Financial Development, NARDL, Türkiye*

JEL Codes**:** *C22, O44, Q56, F18*

Türkiye'de Finansal Gelişme CO_2 Emisyonlarını Asimetrik Olarak Etkiler mi? NARDL Yaklaşımı

Öz

Bu çalışma, 1976-2024 dönemi için Türkiye'de finansal gelişme, ekonomik büyüme, ticari dışa açıklık ve enflasyonun CO2 emisyonları üzerindeki asimetrik etkilerini doğrusal olmayan gecikmeli dağıtılmış otoregresif (NARDL) yaklaşımıyla incelemektedir. Sınır testi, değişkenler arasında bir eşbütünleşme ilişkisi olduğunu doğrulamaktadır. Ampirik bulgular, uzun dönemde finansal gelişmeye yönelik negatif şokların emisyonları anlamlı biçimde artırdığını, pozitif şokların ise anlamlı bir etkisi olmadığını göstermektedir. Benzer şekilde, uzun dönemde ticari genişleme emisyonları artırırken, ticaret hacmindeki daralmalar emisyonları azaltmamaktadır; kısa dönemli ticari etkiler ise simetriktir. Bu durum, kredi daralmalarının çevresel kaliteyi olumsuz etkilediğine işaret etmektedir. Pozitif enflasyon şokları kısa dönemde emisyonları geçici olarak artırsa da, uzun dönemde toplam talebin daralması yoluyla emisyonları azaltır. Genel olarak sonuçlar, Türkiye'de finansal istikrarı da dikkate alan doğrusal olmayan politika çerçevelerine ihtiyaç olduğunu göstermektedir.

Anahtar Sözcükler: *CO_2 Emisyonları, Finansal Gelişme, NARDL, Türkiye*

JEL Kodları: *C22, O44, Q56, F18*

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1. Introduction

Over the past fifty years, Türkiye has experienced sustained economic growth alongside major shifts in trade policy, financial liberalization, and energy consumption. Its macroeconomic structure has evolved considerably, from the export-oriented reforms initiated in the 1980s to the subsequent deepening of financial liberalization. This process was often accompanied by periods of high inflation. Each of these structural transitions likely affected Türkiye's carbon emissions in different ways.

A substantial body of empirical research has investigated the changing interplay between macroeconomic performance and environmental quality. The EKC hypothesis posits that the association between economic growth and environmental degradation follows an inverted-U shape, whereby environmental deterioration increases during the early stages of economic development but subsequently diminishes as countries reach higher income levels (Grossman & Krueger, 1991). Pollution intensifies during the initial stages of growth, then declines after income reaches a certain threshold. Although widely debated and tested, the hypothesis remains inconclusive in many developing economies, where the turning point is often difficult to identify (Sirag et al., 2018; Pata, 2019; Alkan & Bulut, 2022; Guliyev & Seyfullayev, 2025; Koç et al., 2025).

Financial development is also closely linked to environmental outcomes. A more developed financial sector can support cleaner technologies and green infrastructure by channeling capital into environmental innovation. At the same time, broader access to credit can fuel carbon-intensive consumption and production, potentially increasing emissions (Tamazian et al., 2009; Shahbaz et al., 2013). Emerging empirical evidence indicates that the environmental effects of financial expansion and contraction may be asymmetric and vary across countries (Majeed et al., 2020; Raggad, 2020; Ling et al., 2021).

The existing literature on the finance–environment nexus in Türkiye largely relies on symmetric ARDL or VECM frameworks, which assume that macroeconomic expansions and contractions have identical environmental effects (Dar & Asif, 2018; Gokmenoğlu & Sadeghieh, 2019). Departing from this linear approach, this study contributes to the literature by introducing inflation as an asymmetric determinant of environmental degradation, alongside the finance-growth nexus (Uysal & Çayır, 2023). Using an updated dataset covering 1976–2024, the study captures Türkiye's major structural transitions, including trade liberalization and periods of high inflation. It also links monetary instability with carbon emissions, offering a policy-relevant framework for coordinating price stability and net-zero objectives.

2. Literature Review

For the past twenty years, extensive empirical inquiries have continuously integrated various macroeconomic forces to map the trajectories of CO_2 emissions. This section presents the literature, organized by the study's explanatory variables.

At the cross-country level, Khan and Öztürk (2021) investigated how financial development directly and indirectly influences CO_2 emissions. Khan and Yoon (2021) indicated that financial instability leads to higher carbon emissions. They based their findings on a panel of 88 developing economies between 1980 and 2014. Regarding the application of nonlinear methodologies, the NARDL framework has emerged as the dominant tool for capturing asymmetric dynamics. Ahmad et al. (2018) applied it in the Chinese context from 1980 to 2014. Their findings yielded no statistically significant evidence of asymmetry. Fu et al. (2022) confirmed this conclusion for China, thereby providing further support for the symmetric-effects hypothesis in that context. Lahiani (2019), however, contributed to the growing evidence on the nonlinear character of the finance–environment nexus in China.

In South Asian contexts, asymmetric effects have been more consistently documented. Majeed et al. (2020) analyzed data from Pakistan from 1972 to 2018 and found that CO_2 emissions were more strongly affected by negative financial shocks than by positive ones. Using data for Pakistan covering the period 2000–2024, Farooq et al. (2025) found that upward financial shocks tended to increase emissions, whereas downward shocks have the opposite effect. Using asymmetric estimation, Rahman et al. (2019) verified the simultaneous validity of the Pollution Haven Hypothesis (PHH) and EKC. Similarly, Neog and Yadava (2020) confirmed the existence of statistically robust long-run asymmetric cointegration in India, noting that the positive component of financial development loses all explanatory power.

In the Middle East and Gulf region, Raggad (2020) found that downward shocks to financial development are significantly associated with changes in CO_2 emissions in Saudi Arabia. Ibrahim et al. (2021) confirmed substantial long-term associations among financial development, growth, and CO_2 emissions in the Gulf states. Hasanov et al. (2024) employed the Asymmetric Pooled Mean Group estimator for GCC economies. They concluded that while financial expansion exerts a comparatively weaker impact on CO_2 emissions, financial contractions trigger a much stronger environmental response, thereby validating asymmetric behavior.

For African economies, Mensah and Abdul-Mumuni (2022) applied a panel NARDL specification to 31 sub-Saharan African countries. They demonstrated that both the expansion and contraction of financial systems significantly affect carbon outcomes. Das et al. (2023) examined Bangladesh from 1980 to 2020 within a nonlinear bound-testing framework. They similarly confirmed that financial development exerted asymmetric influences on emissions. Ling et al. (2021) undertook a study in China that identified the positive effects of financial development. Even after accounting for globalization and abundant natural resources, their study showed that there is still significant upward pressure on carbon emissions. Mujtaba and Jena (2021) built on prior asymmetric research, using the NARDL approach. Qalati et al. (2023) compared developed and developing economies. They found that expanding financial activity and trade simultaneously elevate carbon risks in both country groups.

In Turkish literature, most current studies rely on linear forecasting strategies. Dar and Asif (2018) applied threshold cointegration over 1960-2013. They found that advancements in the financial sector actively support improvements in environmental quality in Türkiye (Gökmenoğlu et al., 2021; İlarslan et al., 2022; Ozturk, I. & Acaravci, 2013). Gökmenoğlu and Sadeghieh (2019) identified a positive, long-term correlation between financial indicators and CO_2 emissions. Rjoub et al. (2021) confirmed that the relationship between growth and CO_2 emissions was significantly moderated by financial development between 1960 and 2016. Tatar and Çeştepe (2024) employed the fractional-frequency Fourier ADL cointegration method for the period from 1995 to 2019. The authors determined that greater financial deepening contributed to rising CO_2 emissions. Bayat et al. (2023) identified a positive association between financial development and CO_2 emissions. As a result, they interpreted it as consistent with EKC validity. Uysal and Çayır (2023) applied the NARDL model and established that stock-market-based financial development exerted asymmetric and statistically significant effects on environmental quality.

Several studies point to its emissions-augmenting role. Pata (2019) incorporated trade openness into a bootstrap ARDL framework for Türkiye and confirmed its environmental relevance. Acaroğlu et al. (2023) similarly found that trade liberalization raises CO_2 emissions in Türkiye over the long run. At the global level, Taşdemir (2022) analyzed 87 countries and found that trade openness intensifies pollution in emerging and developing economies while reducing it in advanced ones. The findings suggest a threshold-dependent relationship. Suleman et al. (2024) reinforced this pattern by demonstrating that highly open economies face greater emissions exposure from trade. Mignamissi et al. (2024) validated the PHH for Africa using the STIRPAT framework, confirming that trade openness systematically elevates regional emissions. Mahmood et al. (2019) detected asymmetric trade-related emission effects in Tunisia. Jun et al. (2020) reached similar conclusions for China. Udeagha and Breitenbach (2023) applied the NARDL to the SADC region. They uncovered mixed asymmetric evidence across member states. Vacu-Ngqila and Odhiambo (2025) examined South Africa and found that positive trade shocks result in a short-term reduction in emissions.

Regarding inflation as a determinant of carbon emissions, the literature remains divided. Grolleau and Weber (2024) conducted a broad cross-country analysis spanning 189 nations from 1970 to 2020. They identified a statistically modest inverse nexus between inflation and per capita CO_2 emissions. Ünsal (2025) focused on nine developing economies, including Türkiye, over 1990-2020. Alkan et al. (2024) confirmed this inverse pattern across OECD, G20, and EU member states. In contrast, Zheng et al. (2024) employed the NARDL approach. They analyzed Chinese data. They found that inflation has a positive and statistically significant effect on CO_2 emissions. Alshafeey and Saleh

(2024) identified non-linear emission responses to inflation in the USA, the EU, and China. Akan et al. (2023) revealed that the inflation-emissions relationship varies across stable and shock periods and differs by country income level.

According to Afşar and Yüksel (2022), expansionary financial shocks improve environmental quality, whereas contractionary shocks have a detrimental effect by accelerating carbon emissions. Simsek and Eren (2024) stated that financial development in Türkiye leads to higher CO_2 emissions over time. Consequently, any policy framework aimed at achieving sustainable environmental quality in Türkiye must explicitly incorporate strategies to reduce the adverse environmental effects of both financial development and FDI (Katircioglu & Tasinar, 2017; Pata & Yurtkuran, 2018; Doğanlar et al., 2021; Adebayo et al., 2022; Yıldız, 2023). According to ARDL evidence from Türkiye by Şeyranlıoğlu (2024), financial deepening serves as a long-run mitigant of CO_2 emissions. Aydın (2025) found that price stability lacks a significant direct effect on CO_2 emissions. Furtuna and Atis (2024), examining carbon-intensive economies, uncovered a U-shaped relationship between FDI and CO_2 emissions. Demir (2023) found that long-run income growth increases CO_2 emissions.

Overall, the literature shows a high degree of heterogeneity. Some studies identify financial deepening as a driver of environmental degradation (Shahbaz et al., 2013; Ahmad et al., 2018), whereas others suggest that financial efficiency can support greener investment. These differences appear to reflect methodological choices, sample composition, and countries' levels of development. Against this background, the present study departs from symmetric ARDL and VECM approaches by employing NARDL to separately capture positive and negative shocks. It also integrates inflation as an asymmetric determinant of environmental outcomes, which allows a more comprehensive policy interpretation for Türkiye.

3. Methodology, Variables and Data

This section outlines the methodological framework, variables, and data sources employed in the present study. It provides a detailed exposition of the specific tests and results utilized to assess the statistical significance of the constructed NARDL model.

3.1. Methodology

The empirical investigation utilizes annual time-series data for Türkiye spanning 1976–2024. In this analysis, CO_2 emissions serve as the dependent variable, while real GDP, inflation, trade openness, and financial development are incorporated as key macroeconomic explanatory variables. The relevant annual data were sourced from the World Bank's World Development Indicators and the Electronic Data Delivery System (EVDS) of the Central Bank of the Republic of Türkiye.

All variables are converted into natural logarithms to stabilize variance before running the regressions. To meet the cointegration prerequisite that no variable is integrated of order two (I(2)), stationarity properties are first evaluated via the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. Asymmetric transmissions are subsequently modeled using the nonlinear autoregressive distributed lag (NARDL) approach of Shin et al. (2014).

Once cointegration is established, the NARDL model estimates the long-run parameters and uses Wald restrictions to test for both short- and long-run asymmetric behavior. This formulation determines if CO_2 emissions respond heterogeneously to expansionary versus contractionary shifts in GDP, financial development, trade, and inflation. Model reliability is verified through a comprehensive suite of diagnostic checks specifically testing for serial correlation, heteroskedasticity, and residual normality, complemented by parameter stability graphs and the error-correction coefficient, which captures the transient speed of adjustment.

The baseline log-linear model used to examine the relationship between carbon emissions and the selected macroeconomic variables is specified as follows:

$$lnCO_{2t} = f(lnGDP_t, lnFD_t, lnINF_t, lnT_t) \tag{1}$$

Accordingly, the long-run model can be written as:

$$lnCO_{2t} = \beta_1 + \beta_{GDP} lnGDP_t + \beta_{FD} lnFD_t + \beta_{INF} lnINF_t + \beta_t lnT_t + \mu_t \tag{2}$$

While conventional ARDL specifications assume symmetric interactions, this study adopts the Nonlinear ARDL framework developed by Shin et al. (2014). By decomposing the independent variables into positive and negative partial sums, this methodology enables a distinct examination of the dynamic effects of upward and downward shocks on emissions.

The empirical analysis commences with unit root testing to establish the integration order of each variable, as the cointegration framework strictly stipulates that no series must be integrated of order two (I(2)) or higher. Stationarity is evaluated using both the ADF (Dickey & Fuller, 1981) and PP (Phillips & Perron, 1988) tests. These tests were applied at levels and first differences. The following regression specification forms the basis of the ADF test:

$$\Delta y_t = a + \beta t + \gamma y t_{t-1} + \sum_{i=1}^{p} \delta_j \Delta y_{t-i} + \varepsilon_t \tag{3}$$

The PP test is used to check robustness. It uses a special type of correction to the t-statistic to address problems such as serial correlation and heteroskedasticity, without requiring a specified lag structure. The following regression is estimated using the PP test:

$$y_t = a + \beta y t_{t-1} + \delta(t - \frac{T}{2}) + \varepsilon_t \tag{4}$$

In accordance with econometric standards, the ADF test and the Error Correction Model (ECM) are frequently used to analyze the long-term dynamics of macroeconomic variables. While these techniques are robust in capturing dynamic interactions, traditional linear frameworks often operate under the restrictive assumption of symmetry. To overcome the limitations of conventional linear models and adequately capture structural asymmetries, Shin et al. (2014) extended the original ARDL, and cointegration frameworks developed by Pesaran et al. (1999, 2001).

The empirical long-run asymmetric equation for CO_2 emissions can be specified as follows:

$$lnCO_{2t} = \delta_0 + \delta_1(lnGDP_t^+) + \delta_2(lnGDP_t^-) + \delta_3(lnFD_t^+) + \delta_4(lnFD_t^-) + \delta_5(lnINF_t^+) + \delta_6(lnINF_t^-) + \delta_7(lnT_t^+) + \delta_8(lnT_t^-) + \epsilon_t \quad (5)$$

Here, δ represents the vector of coefficients corresponding to the long-run parameters to be estimated. To capture potential asymmetric dynamics, each explanatory variable is decomposed into its respective positive and negative partial sums:

$$lnGDP^+ = \sum_{i=1}^{t} lnGDP_t^+ = \sum_{i=1}^{t} \max(\Delta lnGDP_i, 0) \quad (6)$$

$$lnGDP^- = \sum_{i=1}^{t} lnGDP_t^- = \sum_{i=1}^{t} \min(\Delta lnGDP_i, 0) \quad (7)$$

$$lnFD^+ = \sum_{i=1}^{t} lnFD_t^+ = \sum_{i=1}^{t} \max(\Delta lnFD_i, 0) \quad (8)$$

$$lnFD^- = \sum_{i=1}^{t} lnFD_t^- = \sum_{i=1}^{t} \min(\Delta lnFD_i, 0) \quad (9)$$

$$lnINF^+ = \sum_{i=1}^{t} lnINF_t^+ = \sum_{i=1}^{t} \max(\Delta lnINF_i, 0) \quad (10)$$

$$lnINF^- = \sum_{i=1}^{t} lnINF_t^- = \sum_{i=1}^{t} \min(\Delta lnINF_i, 0) \quad (11)$$

$$lnT^+ = \sum_{i=1}^{t} lnT_t^+ = \sum_{i=1}^{t} \max(\Delta lnT_i, 0) \quad (12)$$

$$lnT^{-} = \sum_{i=1}^{t} lnT_t^{-} = \sum_{i=1}^{t} \min(\Delta lnT_i, 0) \quad (13)$$

The NARDL framework, introduced and developed by Shin et al. (2014), is presented in the following functional form:

$$\begin{aligned}\Delta lnCO_{2,t} = {} & \vartheta_0 + \vartheta_1 lnCO_{2,t-1} + \vartheta_2(lnGDP_{t-1}^{+}) + \vartheta_3(lnGDP_{t-1}^{-}) + \vartheta_4(lnFD_{t-1}^{+}) \\ & + \vartheta_5(lnFD_{t-1}^{-}) + \vartheta_6(lnINF_{t-1}^{+}) + \vartheta_7(lnINF_{t-1}^{-}) + \vartheta_8(lnT_{t-1}^{+}) \\ & + \vartheta_9(lnT_{t-1}^{-}) + \sum_{i=1}^{m} \gamma_{i1}\Delta lnCO_{2,t-i} + \sum_{i=0}^{n} \gamma_{2i}(\Delta lnGDP_{t-i}^{+}) \\ & + \sum_{i=0}^{p} \gamma_{3i}(\Delta lnGDP_{t-i}^{-}) + \sum_{i=0}^{q} \gamma_{4i}(\Delta lnFD_{t-i}^{+}) + \sum_{i=0}^{r} \gamma_{5i}(\Delta lnFD_{t-i}^{-}) \\ & + \sum_{i=0}^{s} \gamma_{6i}(\Delta lnINF_{t-i}^{+}) + \sum_{i=0}^{t} \gamma_{7i}(\Delta lnINF_{t-i}^{-}) + \sum_{i=0}^{u} \gamma_{8i}(\Delta lnT_{t-i}^{+}) \\ & + \sum_{i=0}^{v} \gamma_{9i}(\Delta lnT_{t-i}^{-}) \\ & + \mu_t \end{aligned} \quad (14)$$

3.2. Variables and Data

This study uses the following variables: CO_2 is measured in metric tons of CO_2 equivalent per capita (Abbasi & Riaz, 2016; Al-mulali and Binti Che Sab, 2012; Shahbaz et al., 2013; Salahuddin et al., 2018; Lv & Li, 2021). We represent economic growth with real GDP per capita in constant 2015 US dollars (Odhiambo, 2009; Shahbaz et al., 2013). rade openness is measured as the sum of exports and imports as a percentage of GDP. Trade openness is measured by the sum of exports and imports and expressed as a percentage of GDP (Hao et al., 2016; Shahbaz et al., 2013; Lv & Li, 2021). Inflation is measured as the annual percentage change in the Consumer Price Index (CPI), a principal indicator of the general price level (Sarwar et al., 2021). Financial development is measured as the ratio of domestic credit extended by banks to the private sector to GDP, expressed as a percentage (Nik et al., 2013). Table 1 presents the variables and their sources.

Table 1

Variables and Sources

Variables	Notation	Measurement	Source
Dependent Variable			
CO_2 Emissions	CO_2	t CO2e/capita	WDI
Independent Variables			
Economic Growth	GDP	GDP per capita (constant 2015 US$)	WDI
Trade Openness	T	Trade (% of GDP)	WDI
Inflation	INF	Consumer prices (annual % growth)	TCMB/EVDS
Financial Development	FD	Domestic credit to private sector by banks (% of GDP)	WDI

The mean value for CO_2 emissions is 3.3747, with a relatively modest standard deviation of 1.1940; economic indicators such as GDP and INF exhibit much higher volatility, as evidenced by their substantial spreads and wide gaps between minimum and maximum values.

Table 2

Descriptive Statistics

Variables	Mean	Max.	Min.	Std. Dev.	Jarque-Bera	Prob.
CO_2	3.3747	5.4750	1.7141	1.1940	3.5811	0.1668
GDP	7485.6	15395	3842	3334.2	6.3285	0.0422
FD	29.914	69.612	13.336	18.314	8.7654	0.0124
T	42.097	79.898	9.0997	15.310	0.1168	0.9432
INF	40.310	105.21	6.2509	29.121	3.6666	0.1598

4. Results and Discussion

To ensure structural reliability within the NARDL specification and safeguard against spurious estimates, we first established the order of integration for each underlying series. The ADF results indicate that the variables in question are non-stationary in levels, a finding corroborated by the PP test results. Both tests confirm that all variables are integrated of order one, I (1). These are systematically documented in Table 3.

Table 3

ADF and PP Test Results

	ADF		PP	
Variables	At Level	At First Dif.	At Level	At First Dif.
$lnCO_2$	-0.8799	-6.4406***	-0.9079	-7.4877***
lnGDP	1.4242	-6.5779***	1.8282	-6.5771***
lnFD	-2.050	-9.2959***	-2.1930	-9.3423***
lnT	-3.1237	-5.5733***	-2.0553	-5.9842***
lnINF	-1.4258	-6.1636***	-1.5221	-6.1590***

Notes: ***, **, * show the significance at the 1%, 5% and 10% levels respectively.
Source: Author's calculation

The results of the ADF and PP unit root assessments, which were conducted at both levels and in first differences, are documented. In contrast, after converting the variables to their first differences, all series become significant at the 1% level in both testing methods. Specifically, the test statistics for *$lnCO_2$, lnGDP*, *lnFD, lnT*, and *lnINF* are highly negative and statistically robust.

The NARDL-bounds testing method was used to assess whether there is a long-term relationship among CO_2, GDP, FD, trade, and inflation. The results are presented in Table 4.

Table 4

Non-linear ARDL Bounds Test Results

				Critical Values %5		Critical Values %10	
Model	F - Statistics	Lag Selection	Lag	I (0)	I (1)	I (0)	I (1)
F (CO_2, GDP, FD, T, INF)	17.7016	SIC	(1,1,0,1,1)	2.11	3.15	1.85	2.85

Notes: All variables were calculated in their natural logarithmic forms.
Source: Author's calculation

The NARDL bounds test shows a strong connection between CO_2, GDP, FD, T, and INF over time. This was determined using the optimal lag structure (1, 1, 0, 1, 1) based on the Schwarz Information Criterion (SIC). The F-statistic of 17.7016 exceeds the upper-bound critical values of 3.15 at the 5% level and 2.85 at the 10% level.

In dynamic macroeconomic frameworks, the transmission speed and structural behavior of shocks can inherently differ across distinct temporal horizons. Therefore, establishing a methodologically rigorous NARDL framework necessitates testing both short-run and long-run asymmetries via separate Wald restrictions.

Table 5
Wald test results

Variables	Chi-square Statistic	df	p-value
Long-run asymmetry			
lnGDP (-1)	0.1571	1	0.6918
lnFD	4.2136	1	0.040**
lnT (-1)	11.976	1	<0.001***
lnINF (-1)	10.784	1	0.001***
Short-run asymmetry			
lnFD (-1)	15.352	1	<0.001***
lnT (-1)	2.1705	1	0.1406
lnINF (-1)	8.2371	1	0.004***

Notes: ***, **, * show the significance at the 1%, 5% and 10% levels, respectively.
Source: Author's calculation

The Wald test indicates no statistical significance of long-run asymmetry ($W_{LRGDP} = 0.1571$). This indicates that, although the point estimates differ, there is no formal confirmation of asymmetry between positive and negative GDP shocks. The Wald test confirms a statistically significant long-run asymmetry for financial development ($W_{LRFD} = 4.2136, p < 0.05$). Asymmetry statistics ($W_{SRFD} = 15.352, p < 0.001$) imply that the short-run Wald statistic indicates that temporary financial shocks and changes in credit supply generate asymmetric adjustments in CO_2 emissions.

Trade openness exhibits fundamentally distinct asymmetric behavior that depends entirely on the time horizon. The null hypothesis of symmetry cannot be rejected ($W_{SRT} = 2.1705, p = 0.1406$), indicating that temporary fluctuations in international trade volumes affect environmental parameters through a symmetric adjustment path. However, in the long-run steady state, the symmetry restriction is rejected at the 1% level ($W_{LRT} = 11.976, p < 0.001$). This temporal divergence indicates that while short-run trade adjustments are linear, the cumulative, structural consequences of trade globalization and liberalization are non-invertible; structural integration into global markets may generate persistent environmental pressures that cannot be symmetrically offset or erased during periods of trade contraction.

Macroeconomic stability, proxied by inflation, demonstrates robust and highly consistent non-linearities across all periods, with symmetry being completely rejected at the 1% level for short-run ($W_{SRINF} = 8.2371, p < 0.01$) and at the 1% level for the long-run spectra ($W_{LRINF} = 10.784, p < 0.01$). This rigorous finding establishes that price instability alters environmental outcomes through structurally uneven pathways. In the short run, inflationary spikes cause sudden adjustments in pricing and production strategies that asymmetrically shock emission behaviors. In the long run, this manifests as asymmetric friction: positive inflationary shocks significantly reduce emissions by suppressing aggregate domestic demand and slowing carbon-intensive consumption, whereas deflationary or price-stable periods do not exert a symmetrical counterbalancing environmental force.

Non-linear ARDL long-run estimate results are presented in Table 6.

Table 6

Non-linear ARDL Long-run Estimate Results

Variable	Coefficient	t-Statistics	p-Value
lnGDP+ (-1)	0.6504	3.4959	0.001***
lnGDP- (-1)	0.7696	2.7895	0.001***
lnFD+	0.0047	0.4099	0.68
lnFD-	0.0514	2.2783	0.02**
lnT+ (-1)	0.1445	3.3195	0.001***
lnT- (-1)	-0.1892	-1.4183	0.16
lnINF+ (-1)	-0.0812	-3.8137	0.001***
lnINF- (-1)	0.0297	1.4760	0.14
C	0.3990	4.1631	0.001***
Diagnostic Tests			
Adjusted R^2	0.5776	J-B normality test (Prob.)	0.6864
F statistic	6.2431***	Serial correlation (Prob.)	0.4420
D-W stat.	1.7541	ARCH heteroskedas. (Prob.)	0.3884

Notes: ***, **, * show the significance at the 1%, 5% and 10% levels respectively.
Source: Author's calculation

In the long run, both positive lnGDP shocks ($lnGDP^{+} = 0.6504, p < 0.01$) and negative growth shocks ($lnGDP^{-} = 0.7696, p < 0.01$) are statistically significant. Financial development exhibits an asymmetric pattern in the long-run relationship. Positive shocks to financial development do not have a statistically significant effect on CO_2 emissions ($lnFD^{+} = 0.0047$). Negative shocks ($lnFD^{-} = 0.0514$) are significant at the 5% level. FD contractions are associated with increased CO_2 emissions, possibly because reduced access to credit constrains investment in cleaner technologies and energy-efficient infrastructure.

Trade openness (*T*) also exhibits asymmetric behavior. Positive shocks to trade ($lnT^{+} = 0.1445$) significantly increase CO_2 at the 1% level. Statistically, there is no notable impact of negative shocks to trade on CO_2 emissions ($lnT^{-} =-0.1892$). This finding suggests that contractions in trade do not necessarily lead to lower emissions. Inflation (INF) also displays a noteworthy pattern. Positive shocks to inflation ($\text{lnINF}^{+} = -0.0812$) significantly reduce CO_2 emissions at the 1% significance level. Rising prices may curtail economic activity and energy demand, thereby lowering emissions. Conversely, negative shocks to inflation ($lnINF^{-} = 0.0297$) show no significant effect.

Table 7
Short-run Estimate Results

Variable	Coefficient	t-Statistics	p-Value
lnGDP-	-0.4831	-2.2110	0.05**
lnFD+ (-1)	-0.0705	-5.6624	<0.001***
lnFD- (-1)	0.1080	6.0521	0.001***
lnINF+ (-1)	0.0697	3.2349	0.002***
lnINF- (-1)	-0.0599	-4.2278	<0.001***
lnT+ (-1)	0.1534	3.2511	0.003***
lnT- (-1)	-0.1620	-2.2267	0.043**
CointEq (-1) / ECT_{t-1}	-0.8848	-10.6053	0.001***

Notes: ***, **, * show the significance at the 1%, 5% and 10% levels respectively.
Source: Author's calculation

The error-correction coefficient is negative and statistically significant at the 1% level ($ECT_{t-1} = -0.8848$), confirming convergence toward the long-run equilibrium. Its magnitude indicates that approximately 88.48% of the preceding period's disequilibrium is corrected within one year.

The coefficient on negative shocks in GDP (*lnGDP*) is -0.4831 and statistically significant at the 5% level ($p < 0.05$). The negative coefficient of $lnGDP^{-}$ suggests that adverse growth shocks are associated with an inverse short-run adjustment in CO_2 emissions, indicating that the response of emissions to economic contractions differs from that to expansions.

Positive shocks ($lnFD^{+}$) that increase *FD* mitigate CO_2 emissions. Conversely, negative shocks ($lnFD^{-} = 0.1080$) increase CO_2 emissions through contractions or downturns in financial markets. Specifically, while financial expansion reduces CO_2 emissions, financial contraction augments them. Given that the coefficients differ in both absolute magnitude and direction, the short-run impact of *FD* on CO_2 emissions is asymmetric. In the short run, positive shocks to trade volume significantly increase the dependent variable ($lnT^{+} = 0.1534$), and negative shocks mitigate CO_2 emissions ($lnT^{-} = -0.1620$). Fluctuations in trade liberalization and foreign trade volume directly shape these short-term dynamics. However, as confirmed by the Wald test results ($W_{SRT} = 2.1705$), these short-run responses follow a symmetric adjustment path, indicating that trade fluctuations do not produce asymmetric environmental effects in the short term.

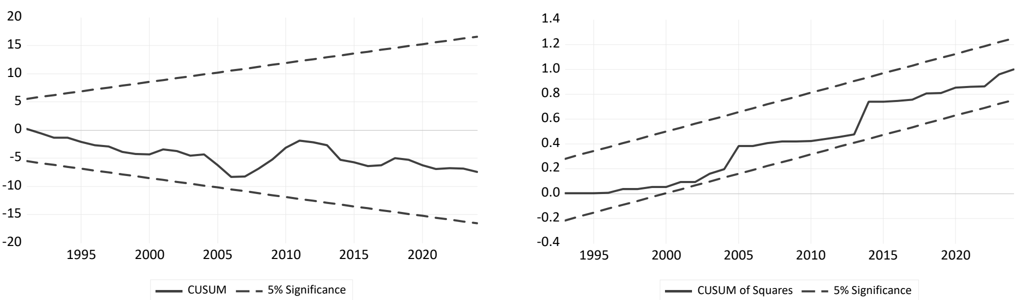
The empirical findings reveal a distinct structural differentiation in the impact of inflation shocks across different time horizons. Positive shocks to inflation ($lnINF^{+}$) exert a positive and statistically significant impact on CO_2 emissions ($lnINF^{+} = 0.0697, p < 0.01$). This short-term positive relationship can be attributed to initial demand-pull pressures and immediate energy-intensive adjustments within the production sector before market agents fully adapt to price instability.

Conversely, in the long run, positive inflation shocks (*lnINF*$^{+}$) are significant (*lnINF*$^{+}$ *=-0.0812, p* <0.01). This long-term reversal aligns perfectly with economic theory: persistent inflationary pressures eventually erode domestic purchasing power, heighten macroeconomic uncertainty, and depress aggregate industrial investment. Consequently, the resulting long-term economic deceleration leads to a structural contraction in industrial activity, thereby driving down aggregate CO_2 emissions over time. This dual-horizon asymmetry highlights the necessity of decomposing price shocks, as transitory short-term environmental degradation shifts toward a contraction-induced decline in emissions.

The model passes all standard diagnostic checks. The residuals are normally distributed ($p = 0.6864$). No evidence of autocorrelation ($p = 0.4420$). The ARCH test confirms the absence of heteroskedasticity in the residuals, supporting the model's assumption of constant variance ($p = 0.3884$). The Durbin-Watson statistic, calculated using the value 1.7541, is close to 2. This further supports the conclusion that there is no autocorrelation. The model explains approximately 57.8% of the variation in CO_2 emissions (Adjusted $R^2 = 0.5776$). Meanwhile, an F-statistic of 6.2431 ($p < 0.01$) verifies the model's overall significance.

Figure 1 presents the CUSUM and CUSUM of Squares stability test results.

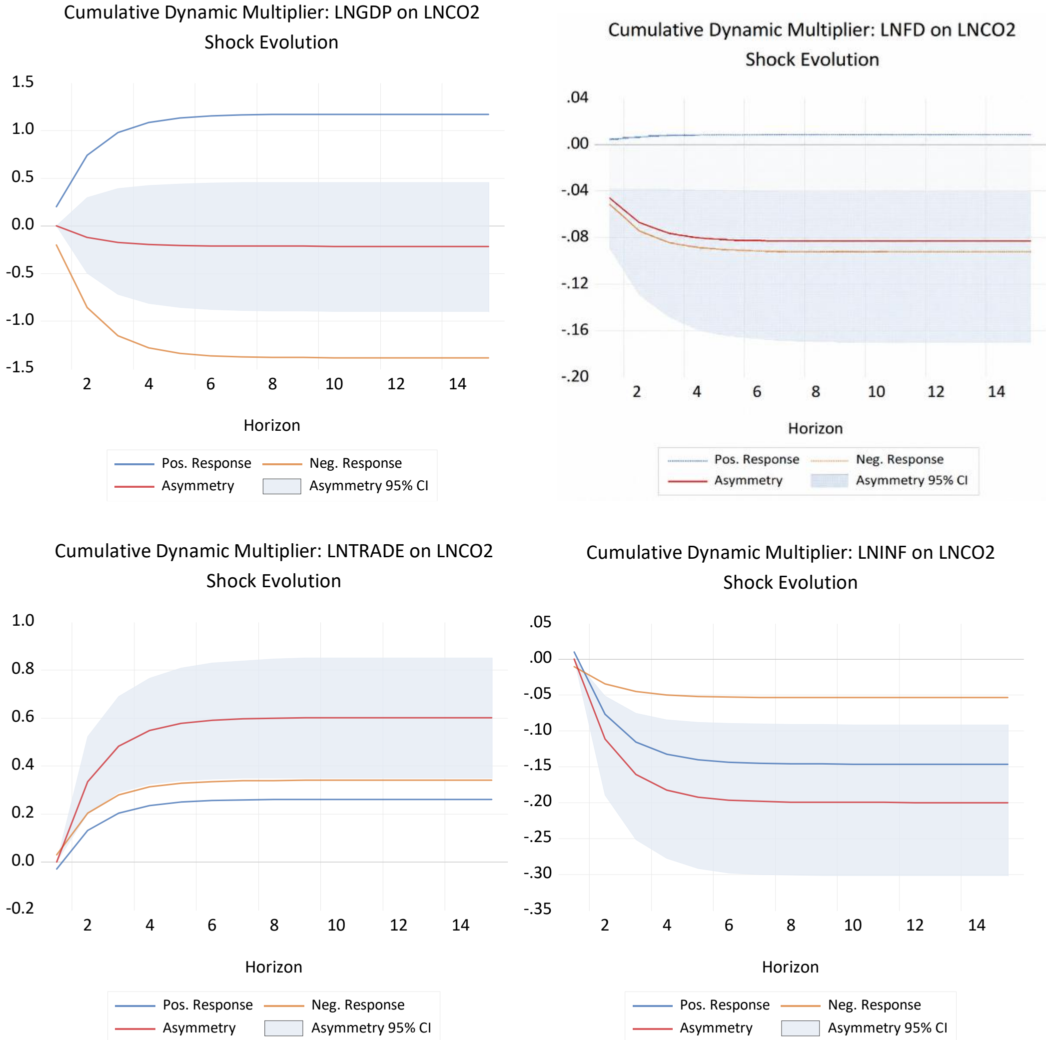
Figure 1
CUSUM and CUSUM of Squares Plots



The CUSUM plots show that the cumulative sums of recursive residuals lie within the critical limits. Consequently, the test statistics remain within the 5% critical bounds, supporting parameter stability over the sample period., indicating that the estimated parameters remain stable and time-invariant throughout the period under analysis. Similarly, the CUSUM of squares test remains within its critical limits, suggesting the absence of abrupt structural changes or instability in the regression equation's variance. Overall, these outputs confirm that the estimated NARDL model is both stable and robust for making inferences. The cumulative dynamic multiplier plots are presented in Figure 2.

Figure 2

The Cumulative Dynamic Multiplier Graphs



The dynamic multiplier graphs confirm the cumulative asymmetric adjustment of CO_2 emissions. Positive and negative trade shocks generate adjustment paths of different magnitudes, confirming the importance of distinguishing between upward and downward changes in trade openness. The positive effect of trade expansion also provides support for the Pollution Haven Hypothesis. Positive inflation shocks reduce emissions through demand contraction, while negative shocks show a weaker, transient effect. These findings reinforce the NARDL results, indicating that symmetric policy frameworks may fail to address Türkiye's actual emission dynamics.

Regarding financial development, the long-run normalized estimates reveal a clear pattern of structural asymmetry. Positive shocks to financial development (lnFD+) do not produce a statistically significant long-run effect on CO_2 emissions, whereas negative shocks to financial development (*lnFD-)* yield a positive and statistically significant long-run impact. Economically, this implies that financial contractions or credit-supply constraints are associated with greater environmental degradation in Türkiye. The underlying transmission mechanism can be explained through corporate survival strategies during credit crunches: when financial markets contract, domestic firms face acute liquidity shortages and high borrowing costs. Consequently, they prioritize immediate operational survival over long-term sustainability, freezing capital-intensive investments in green technology, energy-efficient infrastructure, and cleaner production processes. This finding aligns with Majeed et al. (2020); Raggad (2020); Das et al. (2023); Hasanov et al. (2024) but clarifies the conflicting linear results in the Turkish context, demonstrating that the eco-friendly benefits of financial expansion are erased during periods of financial stress.

The significant influence of *T* on emissions provides empirical support for the validity of the "Pollution Haven Hypothesis" in Türkiye. This finding aligns with the results reported by Mignamissi et al. (2024) in other emerging markets. However, the emissions-reducing effect of positive inflation shocks identified in this study offers a novel perspective that diverges from traditional EKC-focused research. This result suggests that inflationary pressure in Türkiye constrains energy-intensive aggregate demand, a mechanism also noted by Ünsal (2025).

5. Conclusion

This study examined the asymmetric effects of *FD, GDP, T*, and *INF* on CO_2 in Türkiye between 1976 and 2024 using the NARDL framework. The bounds test and the error-correction coefficient confirmed a stable long-run relationship among the variables. They also indicated that Türkiye's growth process continues to cause significant environmental damage. The positive long-run GDP coefficients suggest that economic expansion continues to increase CO_2 emissions, which is broadly consistent with the mixed EKC evidence reported for Türkiye and other developing economies. Türkiye has not yet reached the stage of economic development where environmental improvements occur naturally with rising income (Akça, 2021; Pata, 2019; Acaroğlu et al., 2023; Koç et al., 2025). In the long run, the Wald test results reveal no statistically significant distinction between the effects of positive and negative GDP shocks.

More importantly, the findings indicate that *FD*, *T*, and *INF* each exert distinct, heterogeneous impacts on CO_2 emissions. The finding that negative shocks to financial development increase emissions is consistent with previous NARDL-based evidence indicating that financial system instability or contraction can exacerbate environmental degradation by hindering investment in cleaner technologies and the formation of low-carbon capital (Majeed et al., 2020; Raggad, 2020; Das et al., 2023; Hasanov et al., 2024).

This outcome also helps reconcile the mixed findings in the literature on Türkiye, where certain investigations indicate that economic growth enhances environmental quality, while others document that it increases emissions or has an inconsistent impact on the environment (Dar & Asif, 2018; Gokmenoglu & Sadeghieh, 2019; Bayat et al., 2023; Uysal & Çayır, 2023).

The PHH is validated by the positive effect of trade shocks on CO_2 emissions. While trade openness adjustments exert symmetric environmental effects in the short run, the persistent long-run integration into global markets asymmetrically elevates emissions, underscoring the structural nature of trade-induced environmental degradation. This finding is consistent with evidence reported for Tunisia, China, African economies, highly open economies, and Türkiye (Mahmood et al., 2019; Jun et al., 2020; Mignamissi et al., 2024; Suleman et al., 2024; Pata, 2019; Acaroğlu et al., 2023). Positive inflation shocks are found to reduce emissions. This result is consistent with studies reporting an inverse relationship between inflation and CO_2 emissions. The wider literature also suggests that this relationship varies across countries and time horizons (Grolleau & Weber, 2024; Alkan et al., 2024; Ünsal, 2025; Zheng et al., 2024; Alshafeey & Saleh, 2024).

Overall, the findings imply that Türkiye's emissions dynamics cannot be sufficiently captured under the assumption of symmetry. Policymakers should maintain financial stability and direct credit flows toward green investment. Trade liberalization should be accompanied by strengthened environmental regulations to mitigate the relocation of pollution.

The empirical findings provide important nonlinear policy implications for Türkiye, indicating that conventional symmetric policy responses may be insufficient to achieve environmental objectives. The significant adverse effect of negative financial shocks ($lnFD^{-}$) suggests that credit contractions may push liquidity-constrained firms toward older and more carbon-intensive production technologies. Positive inflation shocks (lnINF^{+}) are found to reduce carbon emissions; this effect should not be interpreted as environmentally desirable, as it likely reflects the contractionary impact of inflationary pressures on aggregate demand, industrial production, and energy use rather than a sustainable climate policy mechanism. Thus, maintaining price stability remains essential for creating a predictable investment environment that supports long-term green transformation.

Despite these findings, the study has certain limitations. The analysis was conducted at an aggregate national level. The study also focuses primarily on CO_2 emissions and a specific set of macroeconomic indicators. Future studies may also employ alternative environmental indicators, such as the ecological footprint, carbon intensity, or sectoral emissions. This study could be expanded upon in future research by employing sectoral-level data or by utilizing panel NARDL methods to compare Türkiye with other MINT (Mexico, Indonesia, Nigeria, Türkiye) or G20 economies. Additionally, incorporating variables related to institutional quality and green technological innovation into the asymmetric framework would provide a more holistic view of the transition toward a low-carbon economy.

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References

Abbasi, F. & Riaz, K. (2016). CO_2 emissions and financial development in an emerging economy: An augmented VAR approach. *Energy Policy*, 90, 102–114. https://doi.org/10.1016/j.enpol.2015.12.017

Acaroğlu, H., Kartal, H. M., & García Márquez, F. G. (2023). Testing the environmental Kuznets curve hypothesis in terms of ecological footprint and CO_2 emissions through energy diversification for Turkey. *Environmental Science and Pollution Research International*, 30, 63289–63304. https://doi.org/10.1007/s11356-023-26278-w

Adebayo, T. S., Agyekum, E. B., Kamel, S., Zawbaa, H. M., & Altuntaş, M. (2022). Drivers of environmental degradation in Turkey: Designing an SDG framework through advanced quantile approaches. *Energy Reports,* 8, 2008-2021. https://doi.org/10.1016/j.egyr.2022.01.020

Afşar, M., & Yüksel, G. Ö. (2022). Küreselleşme, finansal gelişme ve karbon emisyonları ilişkisi: Türkiye üzerine asimetrik kanıtlar. *Sakarya Üniversitesi İktisat Dergisi*, 11(4), 428-449. https://izlik.org/JA53NS37JL

Ahmad, M., Khan, Z., Ur Rahman, Z. & Khan, S. (2018). Does financial development asymmetrically affect CO2 emissions in China? An application of the nonlinear autoregressive distributed lag (NARDL) model. *Carbon Management*, 9(6), 631-644. https://doi.org/10.1080/17583004.2018.1529998

Akan, T., Işık, A.H., Mirzaliyev, N. & Yılmaz, L. (2023). *An Optimal Rate of Inflation for Climate Change Mitigation in Upper-Middle-Income and High-Income Countries?* (May 22, 2023). http://dx.doi.org/10.2139/ssrn.4581563

Akça, H. (2021). Environmental Kuznets Curve and financial development in Turkey: Evidence from augmented ARDL approach. *Environmental Science and Pollution Research International*, 28, 69149-69159. https://doi.org/10.1007/s11356-021-15417-w

Alkan, B., & Bulut, N. (2022). Searching for the existence of the EKC hypothesis in Turkey: An approach using elasticities in the presence of multicollinearity. *Hacettepe Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi,* 40(2), 232-248. https://doi.org/10.17065/huniibf.944180

Alkan, U., Dağdur Şakan, C., Şengül, A. & Ateş, M. H. (2024). The relationship between inflation, human development index and CO_2 in selected country groups. *Maliye Finans Yazıları*, 122, 79-109. https://doi.org/10.33203/mfy.1442703

Al-mulali, U. & Binti Che Sab, C.N. (2012). The impact of energy consumption and CO2 emission on the economic and financial development in 19 selected countries. *Renewable and Sustainable Energy Reviews*, 16(7), 4365-4369. https://doi.org/10.1016/j.rser.2012.05.017

Alshafeey, M. & Saleh, M. A. S. (2024). Assessing inflation and greenhouse gas emissions interplay via neural network analysis: A comparative study of energy use in the USA, EU, and China. *Environmental Sciences Europe*, 36(73), 2-18. https://doi.org/10.1186/s12302-024-00905-w

Aydın, A. (2025). The impact of economic factors on environmental degradation: Price instability, monetary growth and renewable energy investments. *Journal of Economic Studies*, 53(1), 123-134. https://doi.org/10.1108/jes-06-2024-0436

Aydın, Ş., Öztutus, F., & Polat, Ş. H. (2024). The impact of financial development, foreign direct investment and geopolitical risk on CO_2 emissions: Evidence from Turkey. *Fiscaoeconomia*, 8(3), 1617-1640. https://doi.org/10.25295/fsecon.1513450

Bayat, T., Ilarslan, K., & Shahbaz, M. (2023). How do logistics and financial indicators contribute to carbon emissions in Turkiye? *Environmental Science and Pollution Research International*, 30, 97842-97856. https://doi.org/10.1007/s11356-023-29255-5

Dar, J. & Asif, M. (2018). Does financial development improve environmental quality in Turkey? An application of endogenous structural breaks based cointegration approach. *Management of Environmental Quality*, 29(2), 368-394. https://doi.org/10.1108/MEQ-02-2017-0021

Das, A., Brown, L., & McFarlane, A. (2023). Asymmetric effects of financial development on CO_2 emissions in Bangladesh. *Journal of Risk and Financial Management*, 16(5), 269. https://doi.org/10.3390/jrfm16050269

Demir, F. (2023). Asymmetric impact of fiscal policies on environmental deterioration: Evidence from the NARDL model for Türkiye. *Bucak İşletme Fakültesi Dergisi*, 6(2), 226-243. https://doi.org/10.38057/bifd.1350732

Dickey, D.A. & Fuller, W.A. (1981). Likelihood Ratio Statistics for Autoregressive Time Series with Unit Root. *Econometrica,* 49, 1057-1072. http://dx.doi.org/10.2307/1912517

Doğanlar, M., Mike, F., Kızılkaya, O., & Karlılar, S. (2021). Testing the long-run effects of economic growth, financial development and energy consumption on CO2 emissions in Turkey: New evidence from RALS cointegration test. *Environmental Science and Pollution Research*, 28(25), 32554-32563.

Şimşek, O., & Eren, A. A. (2024). Yeşil Ekonomide Ulusal Varlık Fonlarının Rolü. *Bulletin of Economic Theory and Analysis*, 9(3), 627-652. https://doi.org/10.25229/beta.1522373

Farooq, F., Khan, M. R., Hussain, J., & Faheem, M. (2025). Financial development, foreign direct investment, and CO_2 emissions in Pakistan: Evidence from an asymmetric analysis. *Pakistan Journal of Humanities and Social Sciences*, 13(4). https://doi.org/10.52131/pjhss.2025.v13i4.3059

Fu, Q., Wang, J., Xiang, Y., Yasmeen, S. & Zou, B. (2022). Does financial development and renewable energy consumption impact on environmental quality: A new look at China's economy. *Frontiers in Psychology*, 13, 905270,1-12. https://doi.org/10.3389/fpsyg.2022.905270

Furtuna, O. K. & Atis, S. (2024). Does foreign direct investment affect environmental degradation: Evidence from largest carbon intense countries. *PLOS ONE*, 19(12), e0314232. https://doi.org/10.1371/journal.pone.0314232

Gokmenoglu, K. K. & Sadeghieh, M. (2019). Financial development, CO_2 emissions, fossil fuel consumption and economic growth: The case of Turkey. *Strategic Planning for Energy and the Environment*, 38(4), 7-28. https://doi.org/10.1080/10485236.2019.12054409

Gokmenoglu, K.K., Taspinar, N. & Rahman, M.M. (2021). Military expenditure, financial development and environmental degradation in Turkey: A comparison of CO2 emissions and ecological footprint. *International Journal of Finance & Economics*, 26(1), 986-997. https://doi.org/10.1002/ijfe.1831

Grolleau, G. & Weber, C. (2024). The effect of inflation on CO_2 emissions: An analysis over the period

1970–2020. *Ecological Economics*, 216, 108029. https://doi.org/10.1016/j.ecolecon.2023.108029

Grossman, G.M. & Krueger, A.B. (1991). *Environmental Impacts of a North American Free Trade Agreement*. NBER Working Papers 3914, National Bureau of Economic Research.

Guliyev, H. & Seyfullayev, I. (2025). Is the environmental Kuznets curve hypothesis valid for all countries? Fresh insights from bias-corrected dynamic panel data models. *Journal of Environmental Management*, 376, 126960. https://doi.org/10.1016/j.jenvman.2025.126960

Hao, Y., Zhang, ZY., Liao, H., Wei, Y.M. & Wang, S. (2016). Is CO2 emission a side effect of financial development? An empirical analysis for China. *Environ Sci Pollut Res*, 23, 21041–21057. https://doi.org/10.1007/s11356-016-7315-8

Hasanov, F., Shannak, S., Mukhtarov, S. & Suleymanov, E. (2024). Emissions effect of financial development in the GCC: Is the effect asymmetric? *Environmental Economics and Policy Studies*, 28, 119-163. https://doi.org/10.1007/s10018-024-00417-0

Ibrahim, I.D., Hamam, Y., Alayli, Y. (2021). A Review on Africa Energy Supply through Renewable Energy Production: Nigeria, Cameroon, Ghana and South Africa as a Case Study. *Energy Strategy Reviews*, 14 (4), 1-37. https://doi.org/10.1007/s40095-021-00427-8

İlarslan, K., Yıldız, M. & Bayat, T. (2022). Determinants of carbon emissions through the quantile regression method: The case of Turkey. *Eurasian Review of Business & Finance (ERBF),* 4(1), 1-13.

Jun, W., Mahmood, H., & Zakaria, M. (2020). Impact of trade openness on environment in China. *Journal of Business Economics and Management*, 21(4), 1185-1202. https://doi.org/10.3846/jbem.2020.12050

Katircioğlu, S. T. & Taşpinar, N. (2017). Testing the moderating role of financial development in an environmental Kuznets curve: Empirical evidence from Turkey. *Renewable and Sustainable Energy Reviews*, 68, 572-586. https://doi.org/10.1016/j.rser.2016.09.127

Khan, M. & Ozturk, I. (2021). Examining the direct and indirect effects of financial development on CO_2 emissions for 88 developing countries. *Journal of Environmental Management*, 293, 112812. https://doi.org/10.1016/j.jenvman.2021.112812

Khan, M. & Yoon, S.-M. (2021). Financial instability and environmental degradation: A panel data investigation. *Applied Economics*, 53(49), 5682-5696. https://doi.org/10.1080/00036846.2021.1937508

Koç, Ş. E., Koç, N., Çiçek, U. & Bütrak, O. O. (2025). An empirical study on the environmental effects of agricultural value-added, industrialization, and economic growth in Turkey. *International Journal of Energy Economics and Policy*, 15(5), 169-178. https://doi.org/10.32479/ijeep.20461

Lahiani, A. (2019). Is financial development good for the environment? An asymmetric analysis with CO_2 emissions in China. *Environmental Science and Pollution Research International*, 27, 7759-7769. https://doi.org/10.1007/s11356-019-07467-y

Ling, G., Razzaq, A., Guo, Y., Fatima, T. & Shahzad, F. (2021). Asymmetric and time-varying linkages between carbon emissions, globalization, natural resources and financial development in China. *Environment, Development and Sustainability*, 24, 6702-6730. https://doi.org/10.1007/s10668-021-01724-2

Lv, Z. & Li, S. (2021). How financial development affects CO2 emissions: A spatial econometric analysis. *Journal of Environmental Management,* 277, 111397. https://doi.org/10.1016/j.jenvman.2020.111397

Mahmood, H., Maalel, N. & Zarrad, O. (2019). Trade openness and CO_2 emissions: Evidence from Tunisia. *Sustainability*, 11(12), 3295. https://doi.org/10.3390/SU11123295

Majeed, M. T., Samreen, I., Tauqir, A. & Mazhar, M. (2020). The asymmetric relationship between financial development and CO_2 emissions: The case of Pakistan. *SN Applied Sciences*, 2, 827. https://doi.org/10.1007/s42452-020-2627-1

Mensah, B. D. & Abdul-Mumuni, A. (2022). Asymmetric effect of remittances and financial development on carbon emissions in sub-Saharan Africa: An application of panel NARDL approach. *International*

Journal of Energy Sector Management, 17(4), 793-817. https://doi.org/10.1108/ijesm-03-2022-0016

Mignamissi, D., Possi Tebeng, E. X. & Momou Tchinda, A. D. (2024). Does trade openness increase CO_2 emissions in Africa? A revaluation using the composite index of Squalli and Wilson. *Environment Systems and Decisions*, 44, 126-147. https://doi.org/10.1007/s10669-023-09962-7

Mujtaba, A. & Jena, P. (2021). Analyzing asymmetric impact of economic growth, energy use, FDI inflows, and oil prices on CO_2 emissions through NARDL approach. *Environmental Science and Pollution Research International*, 28, 30873-30886. https://doi.org/10.1007/s11356-021-12660-z

Neog, Y. & Yadava, A. K. (2020). Nexus among CO_2 emissions, remittances, and financial development: A NARDL approach for India. *Environmental Science and Pollution Research International*, 27, 44230-44244. https://doi.org/10.1007/s11356-020-10198-0

Nik, A.H., Zahra, S.N., Yunes, S. & Nima, S. (2013). The relationship between financial development indicators and human capital in Iran. *Management Science Letters*, 3(4), 1261-1272. https://doi.org/10.5267/j.msl.2013.02.020

Odhiambo, N.M. (2009). Finance-growth-poverty nexus in South Africa: a dynamic causality linkage. *The Journal of Socio-Economics*, 38(2), 320-325. https://doi.org/10.1016/j.socec.2008.12.006

Ozturk, I., & Acaravci, A. (2013). The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. Energy economics, 36, 262-267.

Pata, U. (2019). Environmental Kuznets Curve and trade openness in Turkey: Bootstrap ARDL approach with a structural break. *Environmental Science and Pollution Research International*, 26, 20264-20276. https://doi.org/10.1007/s11356-019-05266-z

Pata, U. K., & Yurtkuran, S. (2018). Yenilenebilir enerji tüketimi, nüfus yoğunluğu ve finansal gelişmenin CO2 salımına etkisi: Türkiye örneği. *Uluslararası İktisadi ve İdari İncelemeler Dergisi*, 303-318. https://doi.org/10.18092/ulikidince.441173

Pesaran, M. H., Shin, Y. & Smith, R. J. (2001). Bounds testing approaches the analysis of level relationships. *Journal of applied econometrics*, 16(3), 289-326. http://dx.doi.org/10.1002/jae.616

Pesaran, M. H., Shin, Y., & Smith, R. P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. Journal of the American statistical Association, 94(446), 621-634. https://doi.org/10.1080/01621459.1999.10474156

Phillips, P. C. B. & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika*, 75(2): 335-346. https://doi:10.1093/biomet/75.2.335

Qalati, S. A., Kumari, S., Tajeddini, K., Bajaj, N. K. & Ali, R. (2023). Innocent devils: The varying impacts of trade, renewable energy and financial development on environmental damage. *Journal of Cleaner Production*, 386, 135729. https://doi.org/10.1016/j.jclepro.2022.135729

Raggad, B. (2020). Economic development, energy consumption, financial development, and carbon dioxide emissions in Saudi Arabia: New evidence from a nonlinear and asymmetric analysis. *Environmental Science and Pollution Research International*, 27, 21872-21889. https://doi.org/10.1007/s11356-020-08390-3

Rahman, Z. U., Wu, C., & Ahmad, M. (2019). An (a)symmetric analysis of the pollution haven hypothesis in the context of Pakistan: A non-linear approach. *Carbon Management*, 10(3), 227-239. https://doi.org/10.1080/17583004.2019.1577179

Rjoub, H., Odugbesan, J. A., Adebayo, T. & Wong, W. (2021). Sustainability of the moderating role of financial development in the determinants of environmental degradation: Evidence from Turkey. *Sustainability*, 13(4), 1844. https://doi.org/10.3390/SU13041844

Salahuddin, M., Alam, K., Ozturk, I. & Sohag, K. (2018). The effects of electricity consumption, economic growth, financial development and foreign direct investment on CO2 emissions in Kuwait. *Renewable and Sustainable Energy Reviews*, 81(P2), 2002-2010. https://doi.org/10.1016/j.rser.2017.06.009

Sarwar, A., Khan, M.A., Sarwar, Z. & Khan, W. (2021). Financial development, human capital and its impact on economic growth of emerging countries. *Asian Journal of Economics and Banking*, 5(1), 86-100. https://doi.org/10.1108/AJEB-06-2020-0015

Şeyranlıoğlu, O. (2024). Türkiye'de finansal gelişmenin karbon (CO2) emisyonlarına etkisi: Çevresel kuznets eğrisi hipotezi çerçevesinde sektörel bir bakış. *Sosyoekonomi*, 32(61), 427-454. https://doi.org/10.17233/sosyoekonomi.2024.03.20

Shahbaz, M., Hye, Q.M.A., Tiwari, A.K. & Leitão, N.C. (2013). Economic growth, energy consumption, financial development, international trade and CO2 emissions in Indonesia. *Renewable and Sustainable Energy Reviews*, 25(C), 109-121. https://doi.org/10.1016/j.rser.2013.04.009

Shin, Y., Yu, B. & Greenwood-Nimmo, M. (2014). *Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework*. In R. C. Sickles & W. C. Horrace (Eds.), Festschrift in honor of Peter Schmidt: Econometric methods and applications (pp. 281-314). Springer. https://doi.org/10.1007/978-1-4899-8008-3_9

Sirag, A., Matemilola, B. T., Law, S. & Bany-Ariffin, A. N. (2018). Does environmental Kuznets curve hypothesis exist? Evidence from dynamic panel threshold. *Journal of Environmental Economics and Policy*, 7(2), 145-165. https://doi.org/10.1080/21606544.2017.1382395

Suleman, S., Thaker, H. M. T. & Hoh, C. W. (2024). Is trade relevant to the macro drivers of carbon dioxide emissions? A study of high- and low-trade openness economies. *Natural Resources Forum*, 48(3), 874-896. https://doi.org/10.1111/1477-8947.12543

Tamazian, A., Chousa, J. P. & Vadlamannati, K.C. (2009). Does higher economic and financial development lead to environmental degradation: Evidence from BRIC countries. *Energy Policy*, 37(1), 246-253. https://doi.org/10.1016/j.enpol.2008.08.025

Taşdemir, F. (2022). *Development, trade openness, and pollution: Is there any threshold? In Sustainability in Energy Business and Finance* (pp. 155-177). Springer. https://doi.org/10.1007/978-3-030-94051-5_10

Tatar, H.E. & Çeştepe, H. (2024). Relationship between financial development and carbon emissions: Empirical evidence from Türkiye with fractional frequency Fourier approaches. *Mehmet Akif Ersoy Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 11(3), 1212-1229. https://doi.org/10.30798/makuiibf.1479285

Udeagha, M. C. & Breitenbach, M. (2023). On the asymmetric effects of trade openness on CO_2 emissions in SADC with a nonlinear ARDL approach. *Discover Sustainability*, 4(2), 1-47. https://doi.org/10.1007/s43621-022-00117-3

Ünsal, M. (2025). Effects of inflation, foreign direct investment, energy consumption, and trade openness on CO_2 emissions: Panel data analysis for developing countries. *Siyasal: Journal of Political Sciences*, 34(1). https://doi.org/10.26650/siyasal.2025.34.1536959

Uysal, M., & Çayır, M. (2023). Analysis of the asymmetric relationship between stock markets and environmental quality: An analysis on Turkey. *Theoretical and Applied Economics*, 4(637), 99-118.

Vacu-Ngqila, N. P. & Odhiambo, N. (2025). The asymmetric impact of trade openness on carbon emissions in South Africa. *Facta Universitatis, Series: Economics and Organization*, 22(3), 171-185. https://doi.org/10.22190/fueo250218011v

Yıldız, M. (2023). Türkiye'nin karbon nötrlüğü hedefinde ekonomik faktörlerin rolü. *Ekonomi Politika ve Finans Araştırmaları Dergisi*, 8(1), 102-129. https://doi.org/10.30784/epfad.1207540

Zheng, D., Addas, A., Waseem, L. A., Naqvi, S. A. A., Ahmad, M., & Sharif, K. (2024). The hidden costs of inflation: A critical analysis of industrial development and environmental consequences. *PLOS ONE*, 19(8), e0297413. https://doi.org/10.1371/journal.pone.0297413