

Environmental Effects of Economic Uncertainty and Health Expenditures: Evidence from the ARDL Bounds Testing Approach in Türkiye

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Abstract

This paper examines whether economic uncertainty (WUI) and health expenditures (HE) help explain changes in CO₂ emissions (CO₂) in Türkiye during 1990–2023. WUI is measured using the World Uncertainty Index for Türkiye, and the ARDL bounds testing approach is applied to identify both long-term equilibrium patterns and short-term adjustments. Economic growth and financial deepening are included as control variables. The estimates show that WUI does not produce a statistically detectable effect on CO₂, whereas HE is positively associated with emissions (0.3228). The error-correction coefficient (−0.2608) indicates that about 26% of short-run disequilibria disappear in each period. Overall, the findings suggest that environmental outcomes in Türkiye are shaped more strongly by real and sectoral dynamics than by uncertainty, highlighting the need to align health policies with environmental sustainability objectives.

Keywords: CO₂ Emissions, Economic Uncertainty, Health Expenditures

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1. Introduction

Climate change is commonly understood as persistent shifts in global temperatures and atmospheric conditions over extended periods. From the nineteenth century onward, climate dynamics have been increasingly shaped by

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human activities, with fossil fuel consumption (coal, oil, and natural gas) emerging as a key contributing factor. The combustion of these fuels releases greenhouse gases that retain heat within the atmosphere, accelerating the rise in global temperatures. Within this framework, carbon dioxide and methane emerge as the principal gases contributing to climate change.

Key emission sources include the energy, industrial, transportation, building, agricultural, and land-use sectors (UN, 2024). Increasing greenhouse gas concentrations are closely linked to environmental deterioration and pose significant risks to public health and overall human welfare (Danish et al., 2017; Dritsaki and Dritsaki, 2024). In this context, global warming has been largely attributed to economic expansion, increasing energy consumption, and the intensification of greenhouse gas effects. In response, international policy instruments, particularly the Kyoto Protocol (1997; enforced in 2005), have been introduced to mitigate CO₂ emissions (CO₂).

Among environmental pollutants contributing to climate change, CO₂ accounts for approximately 58.8% of total greenhouse gas emissions, representing the largest share. Fossil fuels constitute the dominant source of CO₂ and overall greenhouse gas emissions, and their impact has increased markedly since the post-1970 period due to accelerated economic growth (Pao et al., 2012). The upward trend in CO₂ has become a critical factor intensifying global warming and environmental decline, with notable implications for human health (Baek, 2016; Danish et al., 2017). In this context, environmental degradation is fundamentally tied to economic processes that depend on the heavy utilization of natural resources, including air, water, and soil (Aye and Edoja, 2018).

The increasing energy consumption required for economic growth intensifies CO₂, deepens climate change, and raises environmental costs (Iqbal et al., 2023). Consequently, worsening air quality and the rising prevalence of environmentally driven health problems place upward pressure on health expenditures (HE) across economies at different stages of development (Alimi et al., 2019; Ullah, 2022). Air pollution reduces human productivity, thereby adversely affecting economic activities in general and industrial production in particular (Hansen and Selte, 2000). In this setting, climate change poses a substantial threat to sustaining long-term economic performance on a global scale (Wang et al., 2020). In recent periods, greenhouse gas emissions have remained a central issue on the international agenda for policymakers, researchers, and civil society organizations (Mutascu, 2022). These global developments require a more detailed examination of environmental issues in developing economies such as Türkiye, where rapid economic growth occurs alongside increasing energy demand and rising HE.

Türkiye is among developing economies that have recorded a substantial rise in CO₂ over the last three decades, largely driven by rapid economic expansion, urbanization, and growing energy demand. Data covering the 1990–2023 period

reveal a persistent increase in per capita CO₂, alongside a noticeable rise in the proportion of HE within GDP, particularly from the early 2000s onward. Specifically, per capita CO₂ in Türkiye increased from approximately 2.77 metric tons to 5.14 metric tons during this period, while the share of total HE in GDP rose from around 2.45% to 4.28%.

At the same time, economic uncertainty (WUI) emerges as a key macroeconomic factor with indirect implications for environmental outcomes through its influence on investment behavior, production structures, and energy consumption. Based on Türkiye-specific data derived from the World Uncertainty Index, developed by Ahir et al. (2022) to capture country-level perceptions of WUI, the index exhibits a fluctuating pattern over the 1990–2023 period. While WUI values remained relatively low, ranging between 0.03 and 0.09 during the 1990s, they increased notably after the 2000s and reached a peak of approximately 0.23 in 2015.

The relatively elevated and volatile trajectory of WUI values since the mid-2010s indicates that WUI has become more influential in shaping macroeconomic and sectoral dynamics in Türkiye. These patterns suggest that the linkage among environmental degradation, HE, and WUI has gained increasing importance in the Turkish context and requires examination within a comprehensive analytical framework. Furthermore, Türkiye's ratification of the Paris Climate Agreement in 2021, together with its declaration of a 2053 net-zero emission target, has further strengthened the relevance of empirical research focusing on the determinants of CO₂ and the effectiveness of environmental policies (Ari, 2023; Batmaz and Sisman-Aydin, 2025).

While prior research has examined the nexus between WUI and CO₂, as well as between HE and CO₂, these relationships have largely been treated independently, and their joint impact in the case of Türkiye remains insufficiently explored. A large portion of the literature examines the relationship between WUI and CO₂ without incorporating HE into the analytical framework (Chen et al., 2021; Dunyo et al., 2024). In contrast, research addressing the environmental implications of HE generally overlooks the role of uncertainty (Çobanoğulları, 2024; Omri et al., 2022; Wang et al., 2019).

The reviewed studies indicate that WUI and HE have generally been analysed as separate channels in explaining CO₂ dynamics. This separation limits the ability to understand whether uncertainty and health-related spending jointly shape environmental outcomes. The present study addresses this limitation by modelling WUI and HE together for Türkiye, while controlling for economic growth and financial deepening.

Real economic activity is represented by GDP growth, which may shape CO₂ through changes in production, energy use, and industrial output. Its inclusion helps distinguish the effects of WUI and HE from the broader influence of

economic expansion. Financial deepening is captured through PSL, defined as private-sector credit relative to GDP. Since credit availability can affect investment, production capacity, and energy demand, PSL is included to improve the identification of the WUI and HE coefficients.

In this research, the ARDL model is implemented using annual data covering the 1990–2023 period. From this standpoint, the analysis introduces a distinct contribution to literature at both conceptual and empirical dimensions by jointly examining the interactions among uncertainty, HE, and environmental indicators in a developing economy setting.

Within this framework, the analysis contributes to policy debates on the environment–health–macroeconomy nexus by employing a comprehensive perspective on the link between WUI, HE, and CO₂ in Türkiye. The relevance of this study stems from its capacity to more effectively evaluate the contribution of HE to environmental sustainability, while treating WUI as a separate macroeconomic determinant. WUI may exert indirect pressure on the scale and allocation of HE by shaping budget planning and expenditure priorities across both public and private sectors. Accordingly, incorporating uncertainty as an independent explanatory variable is crucial for assessing the environmental implications of HE. Accordingly, the findings help clarify how uncertainty and HE affect CO₂ through different transmission channels and support more coordinated environmental, health, and macroeconomic policies.

2. Conceptual Framework and Literature Review

Building on prior research, the study formulates its conceptual framework and research questions while integrating empirical insights on the interconnections between WUI, HE, and CO₂. The evidence points to substantial variation in these relationships across different settings.

WUI and CO₂

Empirical evidence on the WUI–CO₂ nexus has expanded considerably, pointing to heterogeneous and context-specific outcomes. As reported in Table 1, a number of studies identify a negative impact of WUI on CO₂, often attributed to declines in economic activity and reduced energy demand (Borhan et al., 2012; Bekun et al., 2019; Chen et al., 2021). In contrast, other contributions suggest a positive relationship, particularly over the long term, as heightened uncertainty may suppress investment in clean energy and innovation while reinforcing dependence on conventional energy sources (Wang et al., 2020; Anser et al., 2021; Ullah et al., 2022).

Additionally, several contributions highlight the presence of bidirectional causality or statistically insignificant relationships, suggesting that the WUI–CO₂ nexus is not uniform across countries and time periods (Syed et al., 2022; Dunyo et

al., 2024). Overall, the literature indicates that the impact of WUI on CO₂ is shaped by structural factors, policy environments, and energy dynamics, supporting the view that the relationship is nonlinear and varies across empirical contexts. Taking together, the existing evidence suggests that WUI influences environmental outcomes through multiple transmission channels, but the direction and magnitude of its effect remain ambiguous.

H1: WUI has a statistically significant effect on CO₂.

Table 1. Empirical studies on WUI and CO₂

Authors (Year)	Sample	Methodology	Main Findings
Bartleet and Gounder (2010)	OECD countries	Time-series analysis	WUI reduces CO ₂ by dampening economic activity.
Borhan et al. (2012)	Malaysia	ARDL	WUI negatively affects carbon emissions.
Bekun et al. (2019)	Emerging economies	Panel econometrics	Uncertainty suppresses emissions through reduced energy demand.
Adams et al. (2020)	Global sample	Panel VAR	Bidirectional causality between CO ₂ and WUI.
Pirgaip and Dinçergök (2020)	G7 countries	Panel cointegration	Long-run positive relationship between WUI and CO ₂ .
Ulucak & Khan (2020)	OECD countries	Panel econometrics	WUI discourages clean energy R&D, increasing emissions.
Wang et al. (2020)	China	ARDL	WUI increases CO ₂ in the long run.
Anser et al. (2021)	Emerging economies	Panel quantile regression	WUI positively affects environmental degradation.
Cai et al. (2021)	China	Time-series analysis	WUI lowers CO ₂ via constrained production.
Chen et al. (2021)	OECD countries	Panel regression	WUI significantly reduces per capita CO ₂ .
Liu & Zhang (2022)	China	ARDL	WUI negatively affects CO ₂ .
Syed et al. (2022)	Global sample	Panel analysis	WUI and geopolitical risk have heterogeneous effects on CO ₂ .
Udeagha and Muchapondwa (2022)	South Africa	ARDL	WUI increases energy use and CO ₂ .
Ullah et al. (2022)	Global sample	Panel regression	WUI accelerates environmental degradation in both short and long run.
Zahra and Badeeb (2022)	Developing economies	Panel analysis	WUI intensifies environmental degradation over time.
Dunyo et al. (2024)	Less developed countries	Panel analysis	No statistically significant relationship between WUI and CO ₂ .
Selmeý et al. (2023)	OECD countries	Panel regression	Policy uncertainty positively correlates with environmental degradation.

Source: Authors' computation (2025)

HE and CO₂

Compared to the WUI–CO₂ nexus, the literature examining the effect of HE on CO₂ remains relatively limited but has expanded in recent years. As reported in Table 2, empirical findings are similarly mixed and vary across countries and

methodological approaches. Some studies provide evidence that HE contributes to higher emissions, largely due to the energy-intensive nature of healthcare services and infrastructure (Chaabouni et al., 2016; Atuahene et al., 2020; Bu and Ali, 2022). Conversely, other studies suggest that HE may reduce environmental degradation by improving public health systems, increasing environmental awareness, and supporting sustainable development (Bilgili et al., 2021; Ganda, 2021).

Several studies report bidirectional causality or mixed short- and long-run effects, suggesting that the HE–CO₂ relationship is dynamic and highly context-dependent (Wang et al., 2019; Çobanoğulları, 2024). The evidence indicates that HE may either alleviate or intensify environmental pressures, depending on economic structure, policy orientation, and temporal dynamics.

H2: HE has a statistically significant effect on CO₂.

Table 2. Empirical studies on HE and CO₂

Authors (Year)	Sample	Methodology	Main Findings
Chaabouni et al. (2016)	Developing countries	Panel cointegration	HE has a positive and significant effect on CO ₂ .
Apergis et al. (2018)	42 Sub-Saharan African countries	Panel causality analysis	Bidirectional causality between HE and CO ₂ ; long-run estimates indicate a negative effect of HE on emissions.
Zaidi and Saidi (2018)	Global sample	Panel causality	Bidirectional causal relationship between HE and CO ₂ .
Wang et al. (2019)	OECD countries	Panel analysis	Bidirectional causality between HE and CO ₂ .
Atuahene et al. (2020)	Developing economies	Panel regression	HE positively affects CO ₂ .
Erdoğan et al. (2020)	BRICS-T countries	Panel causality	Unidirectional positive causality between CO ₂ and HE found only for China.
Akbar et al. (2021)	33 OECD countries	Panel causality	Strong bidirectional causal relationship between HE and CO ₂ .
Bilgili et al. (2021)	Asian countries	Panel econometrics	Government and private HE reduces CO ₂ ; private health spending has a stronger effect.
Ganda (2021)	BRIC countries	Panel causality	Significant negative bidirectional causality between total HE and CO ₂ .
Bu and Ali (2022)	7 developed countries	Panel cointegration	HE increases CO ₂ and contributes to environmental degradation in the long-run.
Karaaslan and Çamkaya (2022)	Türkiye	ARDL & causality	HE raises CO ₂ in the short run but lowers it in the long run; causality exists.
Omri et al. (2022)	Global sample	Panel econometrics	HE and R&D are key factors linking CO ₂ to health outcomes.
Çobanoğulları (2024)	Türkiye	ARDL	HE reduces CO ₂ in the long run but increase emissions in the short run.

Source: Authors' computation (2025).

Despite this growing body of research, most studies examine the effects of WUI and HE on CO₂ separately. As highlighted in Tables 1 and 2, the joint role of these variables as simultaneous determinants of environmental outcomes remains underexplored. This gap is particularly evident in the context of developing economies such as Türkiye, where WUI, rising HE, and increasing CO₂ interact in complex ways.

3. Methodology

Description of Data

In conducting empirical analysis, this study utilized a data set comprising 34 year-observations spanning the annual data for the period 1990-2023. The variables described in Table 3.

Table 3. Data set

Variables	Symbol	Description	Source
CO ₂ Emissions	CO ₂	Metric tons per capita	World Bank (WB)
Economic Uncertainty	WUI	Index, component T6	www.worlduncertaintyindex.com
Total Health Expenditures	HE	Share in GDP	OECD
Private Sector Loans	PSL	Share in GDP	World Bank (WB)
Economic Growth	GDP	GDP growth percentage	World Bank (WB)

Source: Authors' computation (2025).

All variables are analyzed in their level form, without applying logarithmic transformations, allowing the estimated coefficients to be interpreted as direct unit effects rather than elasticities. CO₂ is expressed in metric tons per capita, while HE and PSL are measured as percentages of GDP. Economic growth is represented by the annual GDP growth rate, and economic uncertainty is proxied by the WUI. This specification facilitates a straightforward interpretation of how changes in explanatory variables influence CO₂. The decision to avoid logarithmic transformation is driven by the nature of the data, as the variables include ratios, percentages, and index values, some of which contain negative observations (GDP growth) or values close to zero (WUI).

The WUI variable is obtained from the World Uncertainty Index developed by Ahir et al. (2022). Unlike narrower uncertainty indicators (Bloom, 2009; Baker et al., 2016), this index captures economic, political, and social dimensions of uncertainty based on country-level reports. Its T6 component is constructed using a weighted moving average procedure. For the empirical analysis, quarterly WUI observations are annualized using the geometric mean over 1990–2023, consistent with previous applications in the literature (Wang, 2020; Li et al., 2021; Su et al., 2023; Zhong et al., 2023).

GDP is considered a structural background variable in determining environmental outcomes and is frequently included in empirical studies on environmental quality. In this context, economic growth can indirectly shape CO₂ through channels such as production scale, technology use, and energy intensity. It allows the analysis to control for short-run economic fluctuations affecting environmental dynamics, thereby enabling a clearer identification of the effects associated with uncertainty and HE.

PSL, measured as a share of GDP, are incorporated into the model as an important control variable reflecting the effects of financial deepening on production structures, investment activity, and energy use. Credit expansion through the banking sector may stimulate industrial production and infrastructure investments, potentially leading to the expansion of energy-intensive activities. Existing empirical evidence indicates that the development of the banking sector and increases in credit volume can exert upward pressure on CO₂ (Obiora et al., 2020; Bayrak, 2024). Moreover, a key motivation for including PSL in the model is to mitigate potential omitted variable bias when estimating the effects of WUI and HE on CO₂. Since credit expansion may be simultaneously related to macroeconomic conditions and environmental indicators, excluding financial variables could result in biased and inconsistent coefficient estimates. Accordingly, explicitly controlling for private sector loans contributes to a more reliable and consistent identification of the environmental effects of uncertainty and HE, while also reducing potential endogeneity concerns arising from the finance–emissions nexus.

Table 4 presents the descriptive statistics for the CO₂, WUI, HE, PSL, and GDP variables employed in the empirical study.

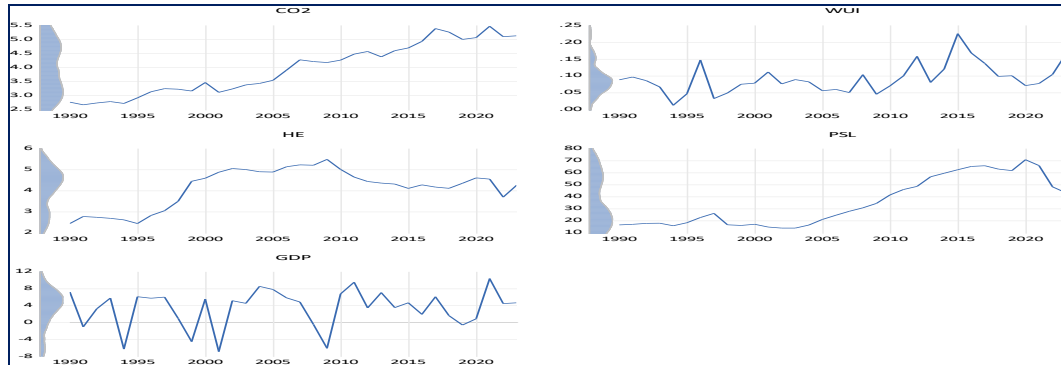
Table 4. Descriptive statistics

Variables	CO₂	WUI	HE	PSL	GDP
Mean	3.960	0.093	4.150	35.380	3.441
Median	4.047	0.085	4.366	27.158	4.682
Maximum	5.474	0.226	5.494	70.897	10.429
Minimum	2.675	0.013	2.446	14.011	-6.916
Standard deviation	0.909	0.044	0.921	19.965	4.444
Skewness	0.123	0.960	-0.633	0.475	-0.920
Kurtosis	1.611	4.159	2.118	1.615	3.175
Observations	34	34	34	34	34

Source: Authors' computation (2025).

Figure 1 illustrates the time paths of CO₂, WUI, HE, PSL, and GDP between 1990 and 2023. CO₂ shows an overall upward trend despite short-term fluctuations, while WUI displays marked volatility around major economic and political events. HE increases sharply after the mid-1990s and remains above its initial level, whereas PSL expands rapidly before declining after 2020. GDP exhibits strong cyclical movements, reflecting Türkiye's exposure to domestic and global shocks.

Figure 1. Change in variables between 1990 and 2023



Source: Authors' computation (2025).

Stationarity Analysis

The integration behavior of CO₂, WUI, HE, PSL, and GDP is assessed before the ARDL estimation. ADF and PP tests are applied under constant and trend specifications to determine whether the series are stationary at level or after first differencing. This procedure verifies that the variables remain within the I(0)–I(1) range required for ARDL bounds testing.

Table 5. Unit root test results (trend and intercept)

Variable	ADF		PP		Result	
	I(0)	I(1)	I(0)	I(1)	ADF	PP
CO ₂	-3.268* (0.089)	-6.209*** (0.000)	-3.345* (0.077)	-7.621*** (0.000)	I(1)	I(1)
WUI	-4.120** (0.014)		-4.055** (0.016)		I(0)	I(0)
HE	-1.240 (0.885)	-4.702*** (0.004)	-1.320 (0.865)	-4.725*** (0.003)	I(1)	I(1)
PSL	-1.590 (0.773)	-3.676** (0.040)	-1.224 (0.889)	-3.676** (0.040)	I(1)	I(1)
GDP	-6.057*** (0.000)		-8.218*** (0.000)		I(0)	I(0)

Note: ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively. Values in parentheses are p-values. Results are reported at the 5% significance level.

Source: Authors' computation (2025).

Table 5 shows that WUI and GDP are stationary in levels, whereas CO₂, HE, and PSL become stationary after first differencing. This mixed I(0)/I(1) structure satisfies the basic requirement for applying the ARDL framework.

Correlation Analysis

Table 6 presents the Pearson correlation matrix used to evaluate potential multicollinearity among the explanatory variables. Although CO₂ and PSL are highly correlated (0.916), this does not directly indicate multicollinearity because CO₂ is the dependent variable. Among the explanatory variables, the strongest correlation is observed between WUI and PSL (0.483), which remains below the 0.80–0.90 threshold generally associated with severe multicollinearity (Kennedy, 2008). Therefore, serious multicollinearity does not appear to be a concern in the model.

Table 6. Correlation matrix

Correlation Variables	CO ₂	WUI	HE	PSL	GDP
CO ₂	1				
WUI	0.449	1			
p-value	0.008***				
HE	0.476	0.069	1		
p-value	0.004***	0.700			
PSL	0.916	0.483	0.237	1	
p-value	0.000***	0.004***	0.177		
GDP	0.178	0.107	-0.021	0.148	1
p-value	0.313	0.547	0.908	0.403	

Note: ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.

Source: Authors' computation (2025).

4. Econometric Model

The econometric model is designed to estimate how WUI and HE affect CO₂ in Türkiye over the 1990–2023 period. Since the unit root results indicate a mixture of I(0) and I(1) variables, the ARDL framework is appropriate for examining both long-run and short-run relationships.

Drawing on the empirical evidence summarized in Tables 1 and 2, the model links CO₂ to WUI, HE, PSL, and GDP. WUI and HE constitute the core variables of interest, while PSL and GDP capture financial deepening and real economic activity, respectively. This relationship is expressed through the functional form in Equation 1 and the baseline empirical model in Equation 2.

$$CO_{2,t} = f(WUI_t, HE_t, PSL_t, GDP_t) \quad (1)$$

$$CO_{2,t} = \alpha_0 + \alpha_1 WUI_t + \alpha_2 HE_t + \alpha_3 PSL_t + \alpha_4 GDP_t + \mu_t \quad (2)$$

In Equation 2, t represents the time period, α_0 is the constant term, $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are the effect size coefficients of the independent variables (WUI, HE, PSL, GDP), and μ_t is the error term.

ARDL Method

The ARDL bounds testing approach is preferred because it allows I(0) and I(1) variables to be modelled jointly, provided that none of the series is I(2) (Pesaran et al., 2001). The method also enables long-run coefficients and short-run adjustment dynamics to be estimated within the same framework through the Unrestricted Error Correction Model (UECM) (Pesaran and Shin, 1998). Equation 3 presents the empirical ARDL specification used in the analysis.

$$\Delta CO_{2,t} = \beta_0 + \beta_1 CO_{2,t-1} + \beta_2 WUI_{t-1} + \beta_3 HE_{t-1} + \beta_4 PSL_{t-1} + \beta_5 GDP_{t-1} + \sum_{i=1}^k \beta_6 \Delta CO_{2,t-i} + \sum_{i=0}^m \beta_7 \Delta WUI_{t-i} + \sum_{i=0}^n \beta_8 \Delta HE_{t-i} + \sum_{i=0}^p \beta_9 \Delta PSL_{t-i} + \sum_{i=0}^r \beta_{10} \Delta GDP_{t-i} + \varepsilon_t \quad (3)$$

In Equation 3, Δ denotes the first-difference operator; β_0 is the intercept; $k-r$ represent the optimal lag lengths selected by the Akaike Information Criterion (AIC); $\beta_1-\beta_5$ capture the long-run coefficients; $\beta_6-\beta_{10}$ represent the short-run dynamics; and ε_t is the error term.

When cointegration is detected, the short-run adjustment process is estimated through the UECM form shown in Equation 4. The ECM term reflects the speed at which deviations from the long-run path are corrected. A negative and statistically meaningful ECM coefficient indicates convergence toward equilibrium (Narayan and Smyth, 2006).

$$\Delta CO_{2,t} = \omega_0 + \sum_{i=1}^w \omega_1 \Delta CO_{2,t-i} + \sum_{i=0}^x \omega_2 \Delta WUI_{t-i} + \sum_{i=0}^y \omega_3 \Delta HE_{t-i} + \sum_{i=0}^z \omega_4 \Delta PSL_{t-i} + \sum_{i=0}^n \omega_5 \Delta GDP_{t-i} + \omega_6 ECM_{t-1} + \lambda_t \quad (4)$$

In Equation 4, ω_0 is the intercept, $\omega_1-\omega_5$ represent short-run coefficients, ω_6 is the adjustment coefficient, $w-n$ denote the selected lag lengths, and λ_t is the disturbance term.

5. Findings

The ARDL bounds test is used to evaluate whether a long-run relationship exists among the variables. Table 7 reports the bounds test and diagnostic results for the selected ARDL specification.

Table 7. ARDL (1, 0, 1, 0, 0) bounds and diagnostic test results

Bounds Test:			
F-statistic value	Significance Level	I(0)	I(1)
7.264	10%	(2.200) [2.460]	(3.090) [3.460]
	5%	(2.560) [2.947]	(3.490) [4.088]
	1%	(3.290) [4.093]	(4.370) [5.532]
Diagnostic Tests:			
Diagnosis	Test Type	F-test statistic	p-value
Model Specification	Ramsey Reset	0.291	0.594
Heteroskedasticity	Breusch-Pagan-Godfrey	0.607	0.722
Autocorrelation	Breusch-Godfrey	0.385	0.765
Normality	Jarque-Bera	4.075	0.130

Note: Brackets indicate the critical values calculated by Pesaran et al. (2001) and square brackets indicate the critical values calculated by Narayan (2005) for $k = 4$ independent variables and $n = 33$ observations. The results include unrestricted constant and unrestricted trend.

Source: Authors' computation (2025).

Table 7 provides strong evidence in favour of a long-run equilibrium relationship among the variables in the Turkish context. The calculated F-statistics consistently surpasses the relevant critical thresholds associated with both I(0) and I(1) across different significance levels, based on Pesaran et al. (2001). Comparable conclusions emerge when using the critical bounds proposed by Narayan (2005), as the test statistics remain above the required limits. These results indicate that WUI, HE, and CO₂ move together in the long run.

The outcomes of the diagnostic checks—Ramsey RESET, Breusch–Pagan–Godfrey, Breusch–Godfrey, and Jarque–Bera—suggest that the model is free from specification issues, with all p-values remaining above 0.10. In addition, the ARDL structure accounts for dynamic behaviour through the inclusion of lagged variables. The corresponding long- and short-run estimates are reported in Table 8.

Table 8. ARDL (1, 0, 1, 0, 0) coefficients

Dependent variable = $\Delta\text{CO}_{2,t}$				
Independent Variables	Coefficient	Std. Error	t-Statistic	p-value
Long-run coefficients				
WUI	-0.1122	2.5713	-0.0437	0.9655
HE	0.3228	0.1159	2.7867	0.0098***
PSL	0.0390	0.0061	6.4547	0.0000***
GDP	0.1002	0.0445	2.2488	0.0332**
C	1.0911	0.5296	2.0604	0.0495**

Short-run coefficients

$\Delta(\text{HE})$	0.2188	0.0757	2.8917	0.0076***
ECM(-1)	-0.2608	0.0362	-7.2087	0.0000***
Adjusted R-squared	0.5659			
Log likelihood	20.8153			
Durbin-Watson	1.9504			

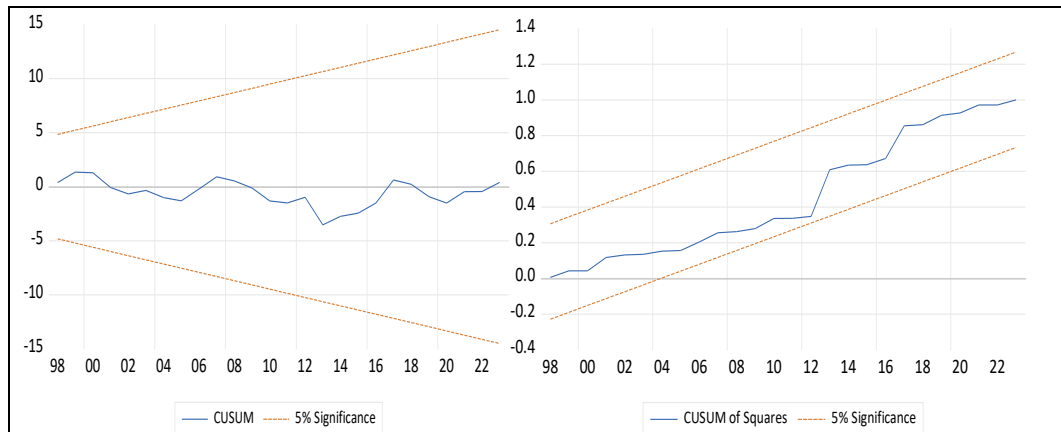
$$\text{CO}_2 = -0.1122 * \text{WUI} + 0.3228 * \text{HE} + 0.0390 * \text{PSL} + 0.1002 * \text{GDP} + 1.0911$$

Note: ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.

Source: Authors' computation (2025).

Table 8 indicates that HE, PSL, and GDP increase CO₂ in the long run, with coefficients of 0.3228, 0.0390, and 0.1002, respectively. HE and PSL are significant at the 1% level, while GDP is significant at the 5% level. WUI, however, has a negative coefficient that is not statistically different from zero. In the short run, only HE remains statistically relevant for CO₂. The ECM coefficient shows that deviations from the long-run path are gradually corrected, with approximately 26.8% of disequilibrium removed in each period. The CUSUM and CUSUMSQ plots in Figure 2 remain within the 5% critical bounds, indicating parameter stability over the sample period (Brown et al., 1975).

Figure 2. ARDL (1, 0, 1, 0, 0) CUSUM and CUSUMSQ plots



Source: Authors' computation (2025).

6. Conclusion and Policy Implications

The ARDL estimates indicate that CO₂ is linked to its determinants over the long run. The WUI coefficient is below zero but not statistically reliable ($\beta = -0.1122$; $p > 0.10$), suggesting that uncertainty has a limited direct role in shaping CO₂ in Türkiye. By contrast, HE has a positive long-run coefficient ($\beta = 0.3228$), implying that higher health spending is accompanied by increased CO₂. This outcome points to the environmental burden associated with the expansion of healthcare-related activity.

The WUI finding is close to the evidence reported by Dunyo et al. (2024), whereas the HE result aligns with previous studies documenting an emission-increasing role of health spending (Wang et al., 2019; Atuahene et al., 2020; Erdoğan et al., 2020; Akbar et al., 2021; Ali, 2022). The short-run HE result is also compatible with evidence from Türkiye-focused studies (Karaaslan and Çamkaya, 2022; Çobanoğulları, 2024).

The statistically insignificant effect of WUI on CO₂ suggests that the environmental consequences of uncertainty may not manifest directly or strongly in every country context. In the case of Türkiye, real economic dynamics such as production structure, energy mix, and sectoral expansion appear to play a more dominant role in shaping environmental outcomes, while uncertainty exerts a more indirect and limited influence. The heavy reliance on fossil fuels in energy consumption and the relatively autonomous design of environmental policies from short-run macroeconomic fluctuations may have weakened the transmission of uncertainty shocks to CO₂. This result underscores the importance of country-specific structural and policy frameworks in determining the environmental impacts of WUI.

The positive relationship between HE and CO₂ can be associated with the inherently energy-intensive nature of healthcare services. In Türkiye, the health transformation program implemented since the early 2000s has led to a substantial expansion of hospital infrastructure, improved access to healthcare services, and increased use of advanced medical technologies, all of which have significantly raised energy demand in the health sector. Rising electricity consumption, heating and cooling requirements in hospitals, and processes related to medical waste disposal constitute key channels through which increases in HE translates into higher CO₂.

When compared with OECD and BRICS countries, the findings related to HE reveals the importance of country-specific structural characteristics. In many OECD countries, widespread energy-efficient healthcare infrastructure, greater use of renewable energy sources, and the implementation of “green hospital” practices help mitigate the environmental impact of health spending. In contrast, BRICS countries exhibit heterogeneous patterns due to differences in public–private health expenditure composition, levels of industrialization, and energy production structures. Türkiye’s rapid expansion of healthcare capacity within a production system largely dependent on conventional energy sources may therefore explain why the estimated effects differ from those observed in OECD economies and some BRICS countries.

The control variables provide further evidence that Türkiye’s environmental outcomes are closely connected to growth and financing conditions. GDP has a positive coefficient ($\beta = 0.1002$; $p < 0.05$), suggesting that higher production activity is accompanied by greater CO₂. PSL also has a positive effect ($\beta = 0.0390$;

$p < 0.01$), indicating that credit expansion may increase emissions by supporting investment and output in energy-demanding sectors. Since Türkiye's production structure remains strongly linked to conventional energy use, growth and financial deepening may reinforce environmental stress unless they are redirected toward cleaner technologies and low-carbon investments.

The short-run estimates also show that changes in HE increase CO₂ ($\beta = 0.2188$; $p < 0.01$), indicating that the environmental effect of health spending emerges not only over the long term but also through immediate adjustments in service activity. The ECM coefficient (-0.2608 ; $p < 0.01$) confirms a gradual return toward equilibrium, with approximately 26% of short-run deviations absorbed in each period.

Taken together, the statistically insignificant effect of WUI and the positive and significant effects of HE, economic growth, and private sector loans suggest that environmental pressures in Türkiye are primarily shaped by real economic expansion and financial deepening rather than by uncertainty shocks. HE, as a largely mandatory and policy-driven component of public spending, can increase independently of uncertainty conditions and amplify CO₂ through energy-intensive infrastructure and service capacity. Similarly, economic growth and credit expansion stimulate production and investment activities, raising energy demand and reinforcing environmental pressures. In this context, the limited direct impact of uncertainty on CO₂ implies that environmental outcomes are driven more by structural growth patterns, financial conditions, and sectoral expansion processes than by short-run fluctuations in expectations.

This study contributes to the literature by jointly examining WUI and HE within a unified ARDL framework and by providing empirical evidence on the environment–health–macroeconomy nexus in Türkiye. The findings emphasize that ensuring environmental sustainability requires a holistic policy approach that accounts not only for uncertainty management but also for the environmental implications of health policies, growth models, and financial expansion. The empirical results demonstrate that increases in HE raises CO₂ in both the short and long run, highlighting the need to restructure the health sector in line with environmental sustainability objectives. Policies promoting energy efficiency investments in hospital infrastructure, expanding the use of renewable energy in healthcare facilities, and integrating “green hospital” practices into policy frameworks could significantly reduce the environmental footprint of health services. In addition, enhancing low-carbon technologies in medical waste management and logistics processes may contribute to limiting emissions associated with healthcare activities. The positive effects of economic growth and private sector loans on CO₂ indicates the necessity of strengthening the environmental dimension of growth and financing policies. When credit expansion is predominantly directed toward energy-intensive sectors, environmental pressures are likely to intensify. Accordingly, directing financial resources toward renewable energy investments, energy efficiency projects, and low-carbon production

technologies is essential. Integrating environmental risk assessments into banking credit evaluation processes and developing green finance instruments could help balance economic growth with environmental sustainability.

The statistically insignificant effect of WUI on CO₂ suggests that environmental outcomes are shaped more by structural and sectoral dynamics than by short-run uncertainty shocks. This finding underscores the importance of designing environmental policies within a long-run, predictable framework that is insulated from short-run macroeconomic fluctuations. Coordinating health, growth, and financial policies with environmental objectives represents a critical policy domain for Türkiye, particularly in light of its commitments under the Paris Climate Agreement and its 2053 net-zero emission target.

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