International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2026, 16(2), 161-167.

Testing the Carbon Hysteresis Hypothesis in Azerbaijan: Evidence from Nonlinear Unit Root Tests

Zuleykha Javanshirova*, Farkhad Mirzayev, Narmin Guliyeva, Namig Bakhishov

Department of Economic Cybernetics, Baku State University, Baku, Azerbaijan. *Email: zuleykha.javanshirova@gmail.com

Received: 03 September 2025 **Accepted:** 04 January 2025 **DOI:** https://doi.org/10.32479/ijeep.22493

ABSTRACT

This study investigates the validity of the carbon hysteresis hypothesis (CHH) in Azerbaijan by employing advanced nonlinear time-series econometric techniques. Using annual CO_2 emissions data from 1901 to 2022, sourced from the Global Carbon Project and Our World in Data, the analysis begins with Harvey (2007) and Harvey et al. (2008) linearity pre-tests, which confirm the nonlinear nature of the emissions series. This finding justifies the application of nonlinear unit root tests—Kapetanios, Shin, and Snell (KSS, 2003), Sollis (2009), and Kruse (2011)—over conventional linear approaches such as Dickey and Fuller (1981), Perron (1989), and Kwiatkowski et al. (1992). The empirical results consistently fail to reject the null hypothesis of a unit root across both symmetric and asymmetric specifications, indicating that Azerbaijan's CO_2 emissions follow a non-stationary process and that carbon hysteresis is present. This persistence suggests that shocks—whether from economic expansion, external crises, or policy interventions—have permanent effects on emissions levels. The study aligns with existing evidence from other oil-exporting economies and highlights the structural challenges of decarbonization in hydrocarbon-dependent contexts. Based on these findings, the paper proposes a set of policy recommendations aimed at long-term decarbonization, renewable energy integration, industrial modernization, and regulatory strengthening, contributing to both the empirical literature on carbon hysteresis and the design of sustainable climate policies.

Keywords: Carbon Hysteresis Hypothesis, Nonlinear Unit Root Tests, CO_2 Emissions, Azerbaijan, Environmental Policy
JEL Classifications: Q54, Q56, C22, C58

1. INTRODUCTION

Climate change is one of the most serious global problems facing humanity in the 21st century. Although the international community, within the framework of the Paris Agreement, has undertaken various commitments to avoid exceeding the 1.5°C temperature increase threshold (Blanchard and Summers, 1986), the actual situation shows that greenhouse gas emissions, particularly carbon dioxide (CO_2) emissions, continue to rise. According to data from the international energy agency (IEA, 2021) and the United Nations (2015), in 2021, global CO_2 emissions increased by 1.5 billion tons, marking the second-largest jump ever recorded in history. The decisions and policies adopted to prevent such increases have so far failed to deliver the expected results. This fact indicates the need for new approaches and explanatory models in the field of climate policy.

In environmental economics, carbon emissions are considered a key indicator of environmental quality. The persistent increase in carbon emissions is not solely driven by technological or economic factors but may also be linked to historical and structural causes. In this context, the carbon hysteresis hypothesis (CHH) is a new and innovative explanatory model in environmental policy. The concept of carbon hysteresis is derived from the "unemployment hysteresis" concept first popularized by Blanchard and summers (Blanchard and Summers, 1986; 1987). They noted that some economic indicators, especially the unemployment rate, do not return to their previous equilibrium levels after economic shocks, but rather settle at a new equilibrium point with long-term effects. When applied to carbon emissions, this concept suggests that if a country's CO_2 emissions continue to grow steadily after a certain shock and do not return to previous levels, this indicates the presence of carbon hysteresis.

The carbon hysteresis hypothesis (CHH) thus puts forward the assumption that if the carbon emission series has a unit root, meaning it is non-stationary and instead of reverting to the mean over time it establishes equilibrium at new levels, then the country's emission process is hysteretic. According to this hypothesis, the behavior of emissions shows weak responses to past shocks and develops along new trajectories over time. Because of these characteristics, the concept of carbon hysteresis can be applied in climate policy as both a diagnostic and prognostic tool.

The study of Azerbaijan in this context holds particular importance. As a regional energy hub, one of the main pillars of Azerbaijan's economy is the oil and natural gas sector, which results in a high share of the country's carbon emissions. According to World Bank data (World Bank, 2021), Azerbaijan's carbon emissions have increased significantly compared to the 1960s. For example, in the 1990s, following the collapse of the Soviet Union and transformations observed in the industrial sector, a slight decrease was recorded. However, since the 2000s, with the rise in energy exports, an increase in CO_2 emissions has also been observed.

The sustainability of this upward trend, i.e. whether CO_2 emissions will return to their previous levels after historical shocks, necessitates testing the Carbon Hysteresis Hypothesis in the national context. If Azerbaijan's economy is also affected by the carbon hysteresis effect, then, in addition to classic carbon reduction policies (e.g., technological modernisation, renewable energy incentives, etc.), more fundamental structural changes and roadmaps are needed. This necessitates altering the current emissions trend and transitioning to a new, more environmentally sustainable development model.

In line with sustainable development goals (SDG 13), concrete measures must be taken at the local and national levels to combat global climate change. In this sense, testing the carbon hysteresis hypothesis is not only academically relevant but also holds practical and strategic importance. If the hysterisis process is confirmed, this means that the climate and energy policies implemented by the Azerbaijani government must be supported by long-term structural changes and institutional reforms.

The main objective of this study is to empirically investigate whether carbon emissions in Azerbaijan are hysteretic using non-linear unit root tests. The non-linear approach allows for more accurate identification of non-linear trend changes and structural breaks in series. If the series contains a unit root and these structural changes form a stable trend, then the carbon hysteresis hypothesis is considered valid. In addition, by determining the direction of the trend in the emission series (positive or negative), it is possible to clarify the direction in which the hysteresis developed.

This work is one of the first systematic studies on this topic in Azerbaijan and has the potential to contribute to regional energy policy and environmental protection mechanisms. While studies on carbon neutrality at the global level have mainly focused on developed countries with large economies, assessing the situation of developing energy-exporting countries is of particular relevance. For this reason, the analysis of Azerbaijan's emissions profile and climate policies within this framework is important from both an academic and practical perspective.

In conclusion, the main question raised in this introductory section is: Is Azerbaijan's economy moving along a hysterical trend in terms of carbon emissions? If the answer is yes, what changes are needed in the country's climate strategies? To find the answers, this study takes an empirical approach and aims to prepare policy recommendations for Azerbaijan by utilising the capabilities of non-linear tests.

2. LITERATURE REVIEW

The Carbon Hysteresis Hypothesis is a relatively new research direction that reflects long-term memory and trend dependence in economic and ecological variables. The basis of this hypothesis is the concept of unemployment hysteresis presented by Blanchard and Summers (1986; 1987). According to them, economic shocks, especially structural changes in the labour market, make it difficult for unemployment to return to its natural level. The application of this hypothesis has since been extended to other economic indicators, including carbon emissions. In the context of oil-exporting economies, several studies have found strong evidence of carbon hysteresis, indicating that heavy dependence on hydrocarbon revenues and carbon-intensive industrial structures tend to reinforce the persistence of CO_2 emissions over time (Baek and Kim, 2013; Shahbaz et al., 2017; Al-Mulali and Ozturk, 2016; Narayan and Popp, 2012).

Properly analysing the behaviour of CO_2 emissions is of great importance in determining environmental protection and sustainable development strategies. The convergence and stationarity characteristics of CO_2 emissions have been extensively analysed in the literature. Strazicich and List (2003) were the first to investigate the stationarity of carbon emissions among industrialised countries and confirmed the existence of convergence tendencies in some countries. Lee and Chang (2009), on the other hand, assessed the convergence of emissions across 21 OECD countries, taking structural breaks into account, and obtained positive results in most cases.

Researchers such as Barassi et al. (2011) and Solarin (2014) have conducted stationarity tests on different continent and country groups and found that the results vary depending on the test methodology used as well as the time range. For example, Solarin (2014) noted that more than 80% of countries in a study conducted on African countries had convergent emission series. Romero-Ávila (2008) investigated stationarity in 23 OECD countries using the KPSS test and obtained positive results in 19 countries.

In recent years, more specific methodological approaches have begun to be applied. The panel KPSS test with multiple structural breaks proposed by Carrion-i-Silvestre et al. (2005) and the Fourier KPSS test developed by Nazlioglu and Karul (2017) are noteworthy examples in this direction. These tests allow for the consideration of both sharp and soft breaks and enable more realistic and robust results in emission series. Bahmani-Oskooee et al. (2014) have opened a new phase in stationarity analysis by presenting panel tests that consider both sharp and soft breaks together.

In the empirical application of KHH, researchers such as Çağlar (2021) and Çağlar and Mert (2022) stand out. Çağlar (2021) tested the carbon hysteresis hypothesis using panel data from countries with different income groups and found that the hypothesis holds true in 52% of low-income countries while 55% of high-income countries were found to be valid. Çağlar and Mert (2022) analysed the five countries with the highest emissions in the world (China, India, the United States, Russia, and Japan) between 1965 and 2020 and determined that the hysteria effect is valid in all of these countries.

The results of these studies also revealed the direction of hysteresis: negative hysteresis was observed in the United States, Japan, and Russia, while positive hysteresis was observed in China and India. This shows that the dynamics of carbon emissions should be characterised not only by the rate of increase but also by the direction of the trend.

The concept of carbon hysteresis is also related to the Environmental Kuznets curve (EKC). According to the EKC hypothesis, although environmental quality deteriorates in the early stages of economic growth, it begins to improve once income reaches a certain level. From this perspective, countries experiencing positive hysteresis are considered to be on the left side of EKC, i.e., countries that have industrialised at the expense of the quality of the environment. Negative hysteria, on the other hand, is characteristic of either non-industrialised countries or developed countries that implement environmentally responsible policies.

Additionally, Payne and Apergis (2021), Nazlioglu et al. (2021), Erdogan and Solarin (2021) have conducted empirical evaluations using a broad country panel, revealing the effects of öphenomenon of hysteresis is closely linked not only to the level of economic development, but also to political will, technological level, and the effectiveness of climate strategies. Furthermore,recent studies such as Adedoyin et al.(2020) and Alola et al. (2021) have highlighted the importance of institutional quality and renewable energy in carbon mitigation.

In conclusion, the literature shows that research in the field of carbon emissions stationarity and hysteresis analysis has developed methodologically. However, there is a noticeable lack of research on countries that are developing in this area, particularly energy-exporting countries. For this reason, Azerbaijan's analysis in this context is important both in terms of filling the gap and preparing practical recommendations for local policymakers.

3. METHODOLOGY

In this study, in order to detect the presence of carbon hysteresis effects, non-linear unit root tests were preferred over traditional linear unit root tests. Environmental indicators such as carbon emissions often exhibit asymmetric and non-linear responses to structural changes, policy interventions, technological transitions, and external shocks. In such series, when the basic assumptions of classical linear tests (Dickey and Fuller, 1981; Perron, 1989; Kwiatkowski et al., 1992) are not met (e.g., symmetric adjustment, single-regime processes), the results provided by these tests may be misleading. Furthermore, since these tests can only investigate whether the series returns to its level in a linear and symmetric manner, they overlook the regime-dependent and threshold-level-dependent dynamics of environmental series such as carbon emissions. The main purpose of the unit root tests is to determine whether the series is stationary or contains a unit root. To account for the carbon emission series, the break points are determined using the global minimization procedure (Bai, 1998; Bai & Perron, 2003a, 2003b).

Before applying the nonlinear unit root tests, it is essential to verify whether the CO_2 emissions series exhibits significant nonlinear behaviour. For this purpose, the nonlinearity pre-tests developed by Harvey (2007) and Harvey et al. (2008) were employed. These tests evaluate the null hypothesis of linearity against the alternative of a nonlinear exponential smooth transition autoregressive (ESTAR) process. Rejection of the null hypothesis at conventional significance levels justifies the use of nonlinear unit root procedures such as the KSS, Sollis, and Kruse tests.

Therefore, the following non-linear unit root tests have been selected to enable a more accurate analysis of carbon hysteresis: The KSS (2003) test is a leading approach among non-linear unit root tests. This test is based on the ESTAR (Exponential Smooth Transition AutoRegressive) structure to test whether the series is mean-reverting in a non-linear manner. The main advantage of the KSS test is that it is based on the assumption that the correction in the series increases as it moves away from the centre. This is particularly meaningful in series such as carbon emissions, where corrective mechanisms only come into play as a result of large shocks.

To account for the smooth structural breaks in the series, a nonlinear approach with a Fourier function is utillized, following the procedure developed by Enders And Lee (2012a, 2012b). The Sollis (2009) test is a structure that builds upon and expands the KSS test. Its most significant contribution is the inclusion of an asymmetric non-linearity assumption. This allows for the analysis of whether the series exhibits different correction speeds in response to upward and downward deviations. This offers a critical advantage in series that respond more slowly to positive shocks (e.g., increases in energy demand) and more quickly to negative shocks (e.g., crisis periods like pandemics), such as in the case of carbon emissions.

The Kruse (2011) test stands out for its high flexibility among non-linear unit root tests. The test can more flexibly test for the presence of a unit root within ESTAR-type non-linearity. Additionally, the Kruse test has stronger asymptotic properties and offers high test power even for small samples. In time series such as carbon emissions, it yields highly useful results when the series contains structural transformations or has a short observation interval.

For each of these tests, the general functional form and testing procedure follow the original specifications proposed in their respective studies. In all cases, the null hypothesis (H_0) assumes that the series contains a unit root (non-stationarity), while the alternative hypothesis (H_1) posits that the series is stationary under a nonlinear adjustment process. Specifically, the KSS (2003) test is based on a symmetric Exponential Smooth Transition Autoregressive (ESTAR) model, assessing mean reversion in a cubic transformation of the series. The Sollis (2009) test extends this by allowing for both symmetric and asymmetric nonlinear adjustments, incorporating quartic terms to capture more complex transition dynamics. The Kruse (2011) test further generalizes the approach by adding a linear term to the nonlinear structure, enabling detection of both symmetric ESTAR-type reversion and linear persistence simultaneously.

The deterministic component (constant or constant and trend) was selected based on both theoretical relevance for environmental time series and empirical model selection criteria. Lag lengths (k) were determined using the Modified Akaike Information Criterion (MAIC), ensuring the removal of residual autocorrelation. For completeness, the mathematical representation of the KSS, Sollis and Kruse tests are given in equations (1), (2) and (3) as:

$$\Delta y_t = \rho y_{y-1}^3 + \sum_{j=1}^{k} \phi_j" y_{t-j} + \varepsilon_t \quad (1)$$

$$\Delta y_t = \rho_1 y_{y-1}^3 + \rho_2 y_{y-1}^4 + \sum_{j=1}^{k} \phi_j" y_{t-j} + \varepsilon_t \quad (2)$$

$$\Delta y_t = \rho_1 y_{y-1}^3 + \rho_2 y_{y-1}^4 + \rho y_{t-1} + \sum_{j=1}^{k} \phi_j" y_{t-j} + \varepsilon_t \quad (3)$$

4. DATA AND EMPIRICAL RESULTS

Following the in-depth discussion of the methodological framework and the selected nonlinear unit root tests, this section proceeds to describe the data utilized in the analysis. The key variables are defined in Table 1, followed by a presentation and interpretation of the empirical findings derived from the applied econometric procedures.

This table was prepared to define carbon emissions (CO_2), the key variable analyzed in the study. The unit for this variable is ton per capita and the time period is 1901-2023. This demonstrates that this is a very long-term dataset, allowing for an in-depth examination of historical trends.

Table 1: Definition of variable

Symbol	Variables	Unit	Period	Definition	Source
CO_2	Carbon emissions	ton per capita	1901-2023	Carbon dioxide (CO_2) emissions rom burning fossil fuels and industrial processes. This includes emissions from transport, electricity generation, and heating, but not land use change	Our world in data (2025)

The definition clearly clarifies that carbon emissions include only CO_2 produced by the combustion of fossil fuels and industrial processes, but not emissions from land-use change. This is a crucial distinction in environmental data analysis, as land-use changes (e.g., deforestation) can also cause significant carbon emissions and, when externalized, can limit the scope of the model.

For the pre-independence period (1901-1991), corresponding to the Soviet Union era, the CO_2 emissions data for Azerbaijan in Our World in Data are reconstructed from aggregate USSR emissions following the methodology of Andres et al. (2012) and Boden et al. (2017). In this approach, total Soviet emissions are downscaled to the Azerbaijani level using proportional allocation methods based on historical energy consumption, fossil fuel production statistics, and population shares derived from the Maddison Project Database. The reconstruction assumes consistent carbon intensity across Soviet republics within each year. All figures are harmonised and expressed in million metric tons of CO_2 (Mt CO_2), with unit conversions performed where necessary (1 Gg = 0.001 Mt).

Our World in Data (2025) is the data source. This source is suitable for academic research because it provides reliable and open data.

The visual representation of the variables and their trends is illustrated in Figure 1.

Before initiating the analytical unit root testing procedure, the Harvey (2007) and Harvey et al. (2008) linearity tests were conducted on the CO_2 emissions series, and the results are reported in Table 2.

The outcomes indicate that the null hypothesis of linearity cannot be accepted, confirming that the CO_2 series exhibits statistically significant nonlinear behavior. This finding provides a methodological justification for bypassing traditional linear unit root tests such as ADF, PP, or KPSS, as they would not be suitable for capturing the nonlinear dynamics inherent in the data. Accordingly, the study proceeds with the application of nonlinear unit root procedures specifically designed to accommodate such characteristics. The empirical results of the study are summarized in Table 4.

Table 2: Descriptive statistics

Descriptive statistics	CO_2
Mean	3.4008
Median	3.4954
Maximum	7.7400
Minimum	0.1743
Standard deviation	2.3781
Coef.of var	0.6993
Skewness	0.2647
Kurtosis	1.8482
Jarque-Bera	8.2356
Probability	0.0163
Observations	123

Table 3: Linearity test results

Variable	Harvey and Leybourne (2007)			Harvey et al. (2008)
CO_2	W* 1%	W* 5%	W* 10%	W_lamda
	145.60	127.28	109.85	18.115

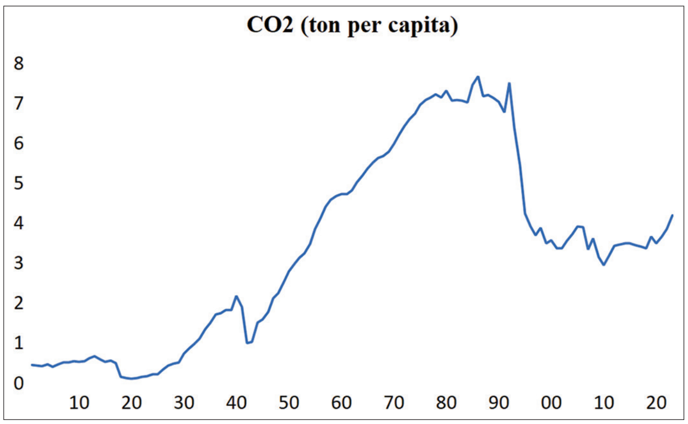
Critical values for Harvey (2007) and Harvey et al (2008) $\chi^2_{4,0.1}=16.85$, $\chi^2_{4,0.05}=19.27$, $\chi^2_{4,0.01}=27.59$, and $\chi^2_{2,0.1}=12.67$, $\chi^2_{2,0.05}=16.83$, $\chi^2_{2,0.01}=20.51$

Table 4 : Unit root results

Variables	KSS (2003)		Sollis (2009)		Kruse (2011)		Results
	Constant						
	Test stat	Lag	Test stat	Lag	Test stat	Lag	
CO_2	−1.6011	1	1.3662	1	2.6167	1	Unit root
Constant and trend							
CO_2	−1.5126	1	1.1394	1	2.4588	1	Unit root

Critical values for the KSS (2003), Sollis (2009), and Kruse (2011) tests at the 1%, 5%, and 10% significance levels are reported in Appendix 1. Lag length was determined using the Akaike ınformation criterion

Figure 1: CO_2 emissions in Azerbaijan (ton per capita, 1901-2023)



The results presented in Table 3 report the outcomes of three nonlinear unit root tests—KSS (2003), Sollis (2009), and Kruse (2011)—applied to the CO_2 emissions series for Azerbaijan, under both constant and constant and trend specifications. Across all three methodologies and both deterministic settings, the null hypothesis of a unit root cannot be rejected at conventional significance levels. This outcome is consistent across symmetric nonlinear adjustment (KSS), asymmetric nonlinear adjustment (Sollis), and the more flexible nonlinear ESTAR framework (Kruse), indicating that the persistence of shocks to the CO_2 emissions series is robust to alternative model specifications.

Specifically, the KSS test statistics (−1.6011 for constant, −1.5126 for constant and trend) fall well short of the critical values required to reject the null, suggesting no mean reversion in a symmetric ESTAR environment. The Sollis test, which accounts for potential asymmetry in the adjustment process, yields statistics of 1.3662 and 1.1394 for the constant and constant and trend models, respectively, again indicating the inability to reject the unit root null. The Kruse test, which offers enhanced power in small samples, also fails to reject the null, with values of 2.6167 and 2.4588 for the respective specifications. The convergence of findings across all tests confirms that the CO_2 emissions series is integrated of order one (I[1]), implying high persistence.

From a hysteresis perspective, these results carry direct implications: Shocks—whether from economic expansion, policy interventions, or external crises—have lasting effects on the level of emissions, with no natural tendency to revert to a pre-shock equilibium. This persistence aligns with the carbon hysteresis hypothesis, wherein historical emissions patterns exert a lasting influence, and current levels are path-dependent on past shocks.

The findings also align with empirical evidence from other oil-exporting economies and directly parallel results from the emerging literature on carbon hysteresis. For instance, Baek and Kim (2013) documented strong hysteresis effects in Middle Eastern oil exporters, where energy price shocks and industrial expansion exerted permanent upward shifts in emissions trajectories. Similarly, Shahbaz et al. (2017) reported that Saudi Arabia's CO_2 emissions follow a non-stationary process, implying that without substantial structural reforms, historical emissions patterns continue to shape current and future levels. In the post-Soviet context, Al-Mulali and Ozturk (2016) identified high persistence in Kazakhstan's emissions, a characteristic closely linked to its hydrocarbon dependence. Furthermore, Narayan and Popp (2012) demonstrated that in the Gulf Cooperation Council (GCC) countries, both market-driven and policy-induced shocks to emissions tend to be permanent rather than transitory.

From the perspective of the carbon hysteresis hypothesis, these outcomes are consistent with empirical findings such as those by Caglar (2022), who explicitly tested for carbon hysteresis in Turkey and found long-run persistence in emissions despite nonlinear adjustments, and Pata and Aydin (2023), who confirmed the hysteresis effect in G7 economies using wavelet-based nonlinear unit root methods. Collectively, these parallels indicate that Azerbaijan's carbon hysteresis is not an isolated case but part of a broader structural pattern common to fossil-fuel-dependent economies, where slow transitions to renewable energy and entrenched carbon-intensive industrial structures perpetuate the permanence of shocks.

5. CONCLUSION AND POLICY RECOMMENDATIONS

The empirical evidence obtained through the application of three distinct nonlinear unit root tests unequivocally supports the presence of a unit root in Azerbaijan's CO_2 emissions series over the observed period. The robustness of this finding across both symmetric and asymmetric adjustment processes underscores the resilience of emission levels to short-term fluctuations and their tendency to embed the effects of past shocks into the long-run trajectory.

From a methodological standpoint, the use of nonlinear testing procedures was instrumental in capturing potential regime-dependent dynamics often overlooked by conventional linear unit root tests. Nonetheless, the results consistently indicate that nonlinearities, if present, do not suffice to induce mean reversion in the CO_2 emissions process.

These findings are in line with previous empirical studies on oil-exporting economies. For example, Baek and Kim (2013) report persistent CO_2 emissions in Middle Eastern oil producers, Shahbaz et al. (2017) identify similar hysteresis dynamics in Saudi Arabia, and Al-Mulali and Ozturk (2016) document high emissions persistence in Kazakhstan. Such parallels suggest that Azerbaijan's emissions trajectory is embedded within a broader structural pattern observed in fossil-fuel-dependent economies, where reliance on hydrocarbon revenues and carbon-intensive industries limits the effectiveness of short-term interventions.

Given this context**,** the results carry important implications for environmental policy: without sustained structural reforms, the historical path of emissions will continue to influence future outcomes, making it imperative to adopt long-term decarbonization strategies, strengthen renewable energy integration, and implement robust regulatory frameworks. Considering the persistence of CO_2 emissions and the absence of spontaneous mean reversion, environmental policy in Azerbaijan must evolve beyond short-term or cyclical interventions. Tackling carbon hysteresis requires a coherent and structural long-term strategy that reshapes the country's energy mix, industrial base, and consumption patterns. In this regard, a series of mutually reinforcing policy actions is essential.

First, a structural transition towards low-carbon and renewable energy sources is indispensable. The unit root nature of emissions suggests that marginal efficiency improvements in fossil fuel-based systems will be insufficient to alter the long-run trajectory. Therefore, large-scale investments in renewable energy infrastructure, coupled with the gradual phase-out of carbon-intensive generation, are necessary for achieving sustained emission reductions.

In addition, the implementation of robust carbon pricing mechanisms—such as carbon taxes or emissions trading systems—can provide continuous economic incentives for reducing emissions. Given that shocks have permanent effects, these mechanisms must deliver credible, predictable, and long-term signals to encourage persistent technological and behavioral change across sectors.

Furthermore, technological innovation and industrial modernization should be prioritized. Deep decarbonization in energy-intensive industries can be fostered through targeted R and D incentives, modernization grants, and the adoption of green production technologies. Such measures would not only reduce carbon intensity but also enhance the competitiveness of domestic industries in a decarbonizing global economy.

Moreover, these efforts must be underpinned by a strong institutional and regulatory framework. Establishing legally binding emission reduction targets, along with transparent and robust monitoring mechanisms, would enhance policy credibility and ensure consistent progress toward decarbonization goals. This institutional backbone is critical for maintaining momentum and avoiding policy reversals.

At the same time, supply-side reforms should be complemented by demand-side measures. Public awareness campaigns, eco-labeling initiatives, and targeted subsidies for energy-efficient appliances can embed low-carbon behaviors within households and firms, creating societal norms that reinforce the structural transition.

Finally, aligning Azerbaijan's policies with global climate commitments, such as the Paris Agreement, can strengthen access to climate finance, enable technology transfer, and position the country as an active participant in the global low-carbon transition. This international engagement not only provides resources and know-how but also reinforces domestic policy credibility.

Evidence from previous studies supports the relevance of these measures in carbon-hysteresis contexts. For instance, Baek and Kim (2013) emphasize the effectiveness of renewable energy expansion in oil-exporting countries with persistent emissions, while Shahbaz et al. (2017) highlight the role of carbon pricing in sustaining long-term reductions. Similarly, Al-Mulali and Ozturk (2016) and Narayan and Popp (2012) show that without institutional reform and technological modernization, oil-dependent economies remain locked in high-carbon trajectories.

In sum, the confirmation of carbon hysteresis in Azerbaijan underscores the urgency of a persistent, comprehensive, and forward-looking climate policy agenda. Without decisive structural reforms, the influence of past emissions will continue to shape future environmental outcomes, locking the economy into a high-carbon trajectory for decades to come.

REFERENCES

Adedoyin, F.F., Bekun, F.V., Sarkodie, S.A. (2020), Economic growth and environmental sustainability nexus: The role of crude oil consumption and energy rents in CO_2 emissions in MENA countries. Environmental Science and Pollution Research, 27, 34645-34660.

Al-Mulali, U., Ozturk, I. (2016), The investigation of environmental Kuznets curve hypothesis in the advanced economies: The role of energy prices. Renewable and Sustainable Energy Reviews, 54, 1622-1631.

Alola, A.A., Donve, T. (2021), The role of renewable and non-renewable energy consumption on Turkey's CO_2 emissions: A revisit of the environmental Kuznets curve hypothesis. Renewable Energy, 172, 308-317.

Andres, R.J., Boden, T.A., Bréon, F.M., Ciais, P., Davis, S., Erickson, D., Gregg, J.S., Jacobso, A., Marland, G., Miller, J., Oda, T., Rayner, P., Treanton, K. (2012), A synthesis of carbon dioxide emissions from fossil-fuel combustion. Biogeosciences, 9(5), 1845-1871.

Baek, J., Kim, H.S. (2013), Is economic growth good or bad for the environment? Empirical evidence from Korea. Energy Economics, 36, 744-749.

Bahmani-Oskooee, M., Halicioglu, F., Neumann, R. (2014), Revisiting purchasing power parity in the commodity-exporting countries: Panel unit root tests with sharp and smooth breaks. Applied Economics, 46(18), 2093-2101.

Bai, J., Perron, P. (1998), Estimating and testing linear models with multiple structural changes. Econometrica, 66(1), 47-78.

Bai, J., Perron, P. (2003a), Computation and analysis of multiple structural change models. Journal of Applied Econometrics, 18(1), 1-22.

Bai, J., Perron, P. (2003b), Critical values for multiple structural change tests. Econometrics Journal, 6(1), 72-78.

Barassi, M.R., Cole, M.A., Elliott, R.J.R. (2011), The stochastic convergence of CO_2 emissions: A long memory approach. Environmental and Resource Economics, 49(3), 367-385.

Blanchard, O.J., Summers, L.H. (1986), Hysteresis and the European unemployment problem. NBER Macroeconomics Annual, 1, 15-90.

Blanchard, O.J., Summers, L.H. (1987), Hysteresis in unemployment. European Economic Review, 31(1), 288-295.

Boden, T.A., Marland, G., Andres, R.J. (1999), Global, Regional, and National Fossil-Fuel Co_2 Emissions (1751-2014). United States: Environmental System Science Data Infrastructure for a Virtual Ecosystem (ESS-DIVE).

Boden, T.A., Marland, G., Andres, R.J. (2017), Global, Regional, and National Fossil-Fuel CO_2 Emissions. United States: Carbon Dioxide Information Analysis Center.

Çağlar, A.E. (2021), Is carbon hysteresis hypothesis valid? Panel evidence from different income groups. Environmental Science and Pollution Research, 28(27), 36045-36055.

Caglar, A.E., Mert, M. (2022), Carbon hysteresis hypothesis as a new approach to emission behavior: A case of top five emitters. Gondwana Research, 109, 171-182.

Carrion-İ-Silvestre, J.L., Del Barrio-Castro, T., López-Bazo, E. (2005), Breaking the panels: An application to the GDP per capita. Econometrics Journal, 8(2), 159-175.

Carrion-I-Silvestre, J.L., Kim, D., Perron, P. (2005), GLS-based unit root tests with multiple structural breaks under both the null and the alternative hypotheses. Econometric Theory, 21(5), 926-949.

Dickey, D.A., Fuller, W.A. (1981), The likelihood ratio statistics for autoregressive time series with a unit root. Econometrica Journal of the Econometric Society, 49, 1057-1072.

Enders, W., Lee, J. (2012a), The flexible Fourier form and the dickey-fuller type unit root tests. Economics Letters, 117(1), 196-199.

Enders, W., Lee, J. (2012b), A unit root test using a Fourier series to approximate smooth breaks. Oxford Bulletin of Economics and Statistics, 74(4), 574-599.

Erdogan, S., Solarin, S.A. (2021), Convergence in carbon emissions: Evidence from 151 countries using the club convergence approach. Environmental Science and Pollution Research, 28, 1845-1862.

Harvey, D.I., Leybourne, S.J., Taylor, A.R. (2007), A simple, robust and powerful multinomial test for linearity against STAR alternatives. Journal of Econometrics, 141(2), 1173-1202.

Harvey, D.I., Leybourne, S.J., Xiao, B. (2008), A powerful test for linearity against symmetric and asymmetric STAR alternatives. Oxford Bulletin of Economics and Statistics, 70(s1), 763-792.

International Energy Agency. (2021), Global Energy Review 2021. France: International Energy Agency.

Kapetanios, G., Shin, Y., Snell, A. (2003), Testing for a unit root in the nonlinear STAR framework. Journal of Econometrics, 112(2), 359-379.

Kruse, R. (2011), A new unit root test against ESTAR alternatives with a non-zero intercept. Economic Modelling, 28(6), 2506-2514.

Kwiatkowski, D., Phillips, P.C., Schmidt, P., Shin, Y. (1992), Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root? Journal of Econometrics, 54(1-3), 159-178.

Lee, C.C., Chang, C.P. (2009), Stochastic convergence of per capita carbon dioxide emissions: A panel unit root test with structural breaks. Applied Economics, 41(22), 2823-2832.

Narayan, P.K., Popp, S. (2012), The energy consumption-real GDP nexus revisited: Empirical evidence from 93 countries. Economic Modelling, 29(2), 303-308.

Nazlioglu, S., Karul, C. (2017), A panel stationarity test with smooth and sharp breaks: Re-investigating the energy-growth nexus. Energy Economics, 65, 356-362.

Nazlioglu, S., Gormus, A., Soytas, U. (2021), Hysteresis in carbon emissions: Evidence from panel stationarity test with structural breaks. Energy Economics, 94, 105076.

Pata, U.K., Aydin, M. (2023), Persistence of CO_2 emissions in G7 countries: A different outlook from wavelet-based linear and nonlinear unit root tests. Environmental Science and Pollution Research, 30(6), 15267-15281.

Payne, J.E., Apergis, N. (2021), Convergence of per capita carbon dioxide emissions among developing countries: Evidence from stochastic and club convergence tests. Environmental Science and Pollution Research, 28(26), 33751-33763.

Perron, P. (1989), The great crash, the oil price shock, and the unit root hypothesis. Econometrica Journal of the Econometric Society, 57, 1361-1401.

Romero-Ávila, D. (2008), Convergence in carbon dioxide emissions among industrialised countries revisited. Energy Economics, 30(5), 2265-2282.

Shahbaz, M., Solarin, S.A., Hammoudeh, S., Shahzad, S.J.H. (2017), Bounds testing approach to analyzing the environment Kuznets curve hypothesis with structural beaks: The role of biomass energy consumption in the United States. Energy Economics, 68, 548-565.

Solarin, S.A. (2014), Convergence of CO_2 emissions in African countries: Evidence from model-based clustering and panel unit root tests. Environmental Science and Pollution Research, 21, 11511-11515.

Sollis, R. (2009), A joint test for a unit root and non-linearity. Econometrics Journal, 12(1), 58-67.

Strazicich, M.C., List, J.A. (2003), Are CO_2 emissions converging? Evidence from 21 OECD countries. Applied Economics Letters, 10(6), 343-347.

United Nations. (2015), Transforming our World: The 2030 Agenda for Sustainable Development. Available from: https://sdgs.un.org/goals

World Bank. (2021), World Development Indicators. Available from: https://databank.worldbank.org/source/world-development-indicators

APPENDIX

Appendix 1: Critical values of KSS, Sollis and Kruse tests

Significance level (%)	KSS		Sollis		Kruse	
	C	C and T	C	C and T	C	C and T
1	−3.48	−3.93	6.88	8.53	13.8	17.1
5	−2.93	−3.40	4.95	6.46	10.2	12.8
10	−2.66	−3.13	4.16	5.46	8.60	11.1