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Reinvestigating the Environmental Kuznets Curve (EKC) Hypothesis with agri-environmental Indicators for Sustainable Growth in the 100th Anniversary of the Republic of Turkiye

Cumhuriyetin 100. Yılında Çevresel Kuznets Eğrisi (EKC) Hipotezinin Tarım-Çevre Göstergeleriyle Sürdürülebilir Büyüme İçin Yeniden İncelenmesi

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Abstract

Purpose: The purpose of this study is to re-investigate the Environmental Kuznets Curve (EKC) hypothesis in Turkey over the period spanning from 2000Q1 to 2020Q4.

Design/Methodology: ARDL analysis was conducted to validate the Environmental Kuznets Curve (EKC) hypothesis considering the agri-environmental indicators reconstructed by utilizing the Principal Component Analysis (PCA) based on 13 variables.

Findings: The results corroborate the Environmental Kuznets Curve (EKC) hypothesis, where initially economic activities boost releases, but sustained investments in cleaner technologies and efficiency eventually improve the environment. The study suggests promoting sustainable agricultural practices, increasing investments in clean technologies and infrastructure, and enhancing regulatory measures to mitigate methane emissions. These results align with and support the existing body of literature.

Limitations: The data limitation of agri-environmental indicators.

Originality/Value: it applies Narayan and Narayan's (2010) alternative method to validate the EKC hypothesis, offers a nuanced, EKC analysis by examining a wide range of environmental indicators following Cole et al. (1997), focuses on agri-environmental indicators to assess Turkey's economic alignment with sustainable development goals, and reconstructs these indicators using Principal Component Analysis (PCA) with 13 variables.

Keywords: EKC hypothesis, Growth, Agri-environmental indicators.

Öz

Amaç: Bu çalışmanın amacı, 2000Q1'den 2020Q4'e kadar olan dönemde Türkiye'deki Çevresel Kuznets Eğrisi (EKC) hipotezini yeniden incelemektir.

Tasarım/Yöntem: EKC hipotezini doğrulamak için, 13 değişkene dayalı olarak Temel Bileşen Analizi (PCA) ile yeniden yapılandırılan tarım-çevre göstergeleri dikkate alınarak Gecikmesi Dağıtılmış Otoregresif Model (ARDL) analizi yapılmıştır.

Bulgular: Sonuçlar, başlangıçta ekonomik faaliyetlerin emisyonları artırdığı, ancak sürdürülebilir yatırımların temiz teknolojilere ve verimliliğe yöneltilmesiyle çevrenin iyileştiği Çevresel Kuznets Eğrisi (EKC) hipotezini doğrulamaktadır. Çalışma, sürdürülebilir tarım uygulamalarının teşvik edilmesini, temiz teknolojilere ve altyapıya yönelik yatırımların artırılmasını ve metan emisyonlarını azaltmak için düzenleyici tedbirlerin güçlendirilmesini önermektedir. Bu sonuçlar, mevcut literatürle uyumlu olup onu desteklemektedir.

Sınırlılıklar: Bu çalışmanın sınırlılıkları, tarım-çevre göstergelerinin veri kısıtlamalarından kaynaklanmaktadır.

Özgünlük/Değer: Bu araştırma, Çevresel Kuznets Eğrisi (EKC) hipotezini doğrulamak için Narayan ve Narayan'ın (2010) alternatif yöntemini kullanmakta, Cole et al. (1997) yöntemini takip ederek geniş bir çevresel gösterge dizisini analiz etmekte, Türkiye'nin ekonomik uyumunu sürdürülebilir kalkınma hedefleriyle değerlendirmek amacıyla tarım-çevre göstergelerine odaklanmakta ve bu göstergeleri 13 değişken kullanarak Temel Bileşen Analizi (PCA) ile yeniden yapılandırmaktadır.

Anahtar Kelimeler: EKC hipotezi, Büyüme, Tarım-Çevre göstergeleri.

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1. GİRİŞ

The EKC hypothesis indicates a nexus that takes on a reverse U-shape between environmental degradation and economic evolution. When the economy grows, environmental degradation increases, but after a certain per capita income level is attained, further economic evolution leads to improvements in environmental quality. This concept derives its name and shape from the original Kuznets curve, introduced by Simon Kuznets, which prescribes a similar nexus between income inequality and economic development (Kuznets,1955). The Kuznets Curve postulates that in the nascent stages of economic growth, industrialization drives increased pollution and resource depletion as economic output is prioritized over environmental concerns. Over time, as income levels rise, societies begin to value environmental quality more highly, leading to increased demand for environmental regulations, cleaner technologies, and a shift towards service-oriented and less polluting industries.

This heightened awareness and incremental action can be observed through three effects, namely, the impact of scale, the impact of composition, and the impact of technology. The impact of scale indicates the bearing of increased economic activity on the environment. Economic growth initially causes higher levels of pollution as more resources are extracted and more waste is produced. However, a composition effect arises as economies evolve and shift from agriculture to manufacturing and then to services. Such structural change can first increase pollution but ultimately leads to cleaner industries eventually dominating the economy. Additionally, the technical effect demonstrates that as income levels increase, economies invest in cleaner technologies and more efficient production processes, thus reducing the environmental impact of economic activities. Collectively, these effects contribute to the reversed form of the (EKC), where pollution levels rise with economic growth to a certain point and then decrease as economies mature and prioritize environmental sustainability (Shafik, 1994; Grossman and Krueger, 1991; Panayotou, 1995).

EKC is explained theoretically. It is notionally drawn from the intersection of marginal cost and marginal benefit curves, thus reflecting the trade-off between economic evolution and environmental quality. It can also be extracted from the technological nexus between consumption and the mitigation of unwanted by-products, indicating that economic growth first leads to environmental degradation, which eventually diminishes as incomes rise and technologies for mitigation improve (Andreoni and Levinson, 2001). This perspective is aligned with both Pareto efficient policies and decentralized market economies since pollution is treated as a factor of production, but its incidence on environmental quality is contingent on the existence of property rights. Such a dynamic process implies the allocation of capital to both production, creating pollution, and environmental sectors, cleaning up or improving the environment. Mitigation expenditures are instrumental in minimizing pollution from production activities, although they may not fully account for long-lived pollutants such as hazardous waste that are not easily mitigated or transported (Gawande et al., 2001). The association between pollution and income can theoretically be identified under different circumstances and interactions between environmental and economic considerations (Dinda, 2004).

Over time, criticisms and revisions of the Kuznets Environmental Curve have arisen. Stern (2004) criticized early EKC studies for methodological deficiencies, such as the use of cross-sectional data that may not accurately capture the dynamic nexus between economic evolution and environmental quality. Stern highlighted the significance of considering non-stationarity in the data and utilizing panel data methods to obtain more reliable results. Narayan and Narayan's (2010) share the view of EKC's weak econometric foundations with Stern. Furthermore, they identify a correlation or multicollinearity in papers that model releases as a function of income utilizing both squared and cubed income variables. Moreover, they identify a major issue when estimating the turning point in the EKC hypothesis, that is, the income level at which economic growth starts to improve environmental quality, since that literature shows unrealistic turning points, thus indicating model misspecification. To rectify that issue, the authors suggest comparing short- and long-run income elasticity, with the smaller long-term elasticity suggesting that economic growth ultimately reduces CO2 emissions. From another point of view, Cole et al. (1997) confirmed that substituting time-series

data with cross-sectional data or replacing global data with regional or country-specific data can produce different turning points and, in some instances, no turning point at all.

Further insights have been provided to this discussion. Galeotti et al. (2006) suggested that developed countries with advanced technology and stringent environmental regulations are more likely to exhibit an EKC pattern, implying that these nations can achieve a reduction in environmental degradation as their economies grow, in contrast to developing countries where such a pattern is not observed. Osabuohien et al. (2013) underscored the importance of strong institutions in mitigating environmental degradation, indicating that robust environmental management policies lead to environmental quality improvements even at low-income levels, with institutional quality significantly modulating the nexus between economic evolution and environmental deterioration in sub-Saharan Africa (SSA). Lipford and Yandle (2010) evaluated EKC in the G8 and five developing countries, concluding that improvements in income alone may not suffice to mitigate global CO2 releases, questioning the usefulness of EKC for carbon emissions. Taguchi (2013) demonstrated that while CO2 releases tend to increase with income, sulfur releases follow the expected inverted U-shape, indicating the need for pollutant-specific policies. The mixed results in the literature do highlight the necessity for further analysis to rigorously test the EKC hypothesis's validity.

This work aligns with Narayan and Narayan (2010), following their alternative method to address the issue of unrealistic turning points, by comparing short- and long-term income elasticity. Moreover, using time-series data, it follows Cole et al. (1997) focusing on country-specific data to provide a more nuanced EKC analysis. The majority of research in the economic literature is concentrating on CO2 releases as a proxy for environmental degradation to test the viability of the EKC. For example, the studies conducted by Işık et al. (2021), Bekun et al. (2021), Alharthi et al. (2021), Touitou & Langarita (2021), Liu (2020), Shahbaz & Sinha (2019) and Farooq et al. (2022). This work will make a difference by considering methane releases as a proxy for environmental degradation. There are two reasons behind our selection. The first reason: Methane has a considerably higher global warming potency than CO2. As per the United Nations Economic Commission for Europe (UNECE), CH4 is 28-36 times more powerful than CO2, on a 100-year timescale. Despite the higher concentration of CO2 in the atmosphere, the contribution of methane to global warming is much more pronounced over the same period, accountable for around 30% of global temperature increases worldwide since the Industrial Revolution, underscoring the urgent need for immediate and sustained reductions in methane emissions to manage short-term global warming and improve air quality (IEA, 2022). With about 40% of anthropogenic methane emissions, the energy sector is a substantial contributor, accounting for an estimated 135 million tons of emissions in 2022 (IEA, 2022). The second reason: Turkiye presents an attractive case study considering its complex energy portfolio and rapid economic transformation, with total GHG emissions increased by 127%. In particular, Methane emissions increased by 41.8%, reaching 60 MtCO2e per year. As per World Bank data, Turkiye's CH4 releases in 2019 were estimated at 49.3 million MtCO2e, ranking the country 35th globally. From 1990 onwards, the agriculture sector has been the dominant source of Turkiye's CH4 releases. The releases from the energy and waste sectors spiked in 2010 and have since fluctuated. However, the Country's National Inventory estimated total methane releases in 2020 at 64 MtCO2e per year, with a notable increase in the waste sector.

According to World Bank statistics, Turkiye's dependence on fossil fuels for energy consumption has significantly contributed to environmental degradation, rising from 62.18% in 1968 to 90.57% in 2008. This figure, however, dropped to 87.59% by 2015, thanks to proactive investments in line with sustainable development goals (WDI, 2018). Whether Turkiye's economic trajectory is aligned with sustainable development goals or whether it is driven by policies that focus primarily on economic growth is very important to assess. In this context, using the PCA method (Principal Component Analysis) and utilizing 13 variables, this study reconstructed the Agri-environmental indicators, which are indispensable for monitoring incorporation of environmental considerations into the Common Agricultural Policy (CAP). These indicators are essential for improving understanding of the environmental impacts of agriculture, guiding policy decisions, and promoting sustainable practices. The relevance of these indicators has been underscored by various European Council commissions, commencing with the Cardiff European Council in 1998 and further promoted by the

Helsinki and Gothenburg Councils, which integrated the environmental aspects into agriculture, associating them with sustainable development strategies and regular reporting. The IRENA, launched in 2002, has been an instrumental step in the development of a comprehensive set of Agri-environment indicators, which serve key purposes such as: offering insights on the state and transformations of the agricultural environment, tracking the environmental impact of agricultural activities, assessing the impact of policies related to agriculture and the environment, shaping policy decisions, illustrating agri-environmental interactions to the public, and enhancing understanding and support for sustainable practices. The potential additions of this manuscript to the current literature can be conceptualized as follows: a) applying Narayan and Narayan's (2010) alternative method to examine the validity of EKC, b) providing a more nuanced EKC analysis by examining a wide range of environmental indicators, following Cole et al. (1997), c) considering agri-environmental indicators to scrutinize compliance of Turkiye's economic trajectory with sustainable development goals, d) reconstructing the agri-environmental indicators using the PCA method (Principal Component Analysis) utilizing 13 variables. This research is arranged as outlined below: Segment 2 comprises the literature review; Segment 3 discusses the data collection and methodological context; Segment 4 introduces the empirical implications; and Segment 5 concludes with basic insights and policy implications.

2. A SUMMARY OF RELEVANT STUDIES

The interconnection between pollution and economic evolution within the context of the EKC hypothesis has been a central area of concentration in environmental economics, in particular, since global warming started to become a critical concern in the early 1990s. While considerable research has investigated CO2 releases, in light of its prominent role in global warming, fewer studies have centered on methane releases, despite methane's pronounced greenhouse mien. This paper seeks to address this gap by utilizing methane releases as an indicator of environmental deterioration. Shokoohi et al. (2022) investigated the bearing of the intensity of energy and economic evolution on the quality of the environment in Iran, Iraq, and Turkiye, assessing the validity of the EKC hypothesis and comparing the ecological footprint (EF) and CO2 releases during the period spanning from 1971 to 2015, utilizing ARDL approach. With both CO2 and EF indicators, the outcomes revealed a reversed U-shaped nexus between income per capita and environmental deterioration in Turkiye, highlighting the energy intensity as a key factor in environmental degradation. Boluk & Karaman (2024) investigated the miens of agriculture, energy usage, and economic expansion on environmental deterioration in Turkiye from 1968 to 2020 by validating the EKC utilizing EF as a sustainability indicator. The EKC hypothesis for Turkiye has been corroborated by the initial outcomes, indicating that environmental degradation initially worsens with economic growth but enhances when GDP achieves higher levels. Elevations in per capita agricultural value added and per capita energy consumption contribute to greater per capita ecological footprints, with energy consumption and agricultural production being the main factors deteriorating environmental quality. The causality analysis demonstrates a growth relationship between GDP and agriculture, as well as between energy consumption and the ecological footprint, suggesting that government policies should prioritize sustainable economic development. The long-term nexus between CO2 releases, energy usage, economic activities, and governance issues had been explored by Ojaghlou et al. (2023) for Turkiye over the period from 1980 to 2021, utilizing the STIRPAT and the EKC hypothesis; and appling dynamic conditional correlation (DCC) and ARDL-linked methodologies. A long-run association between the variables is evident under the STIRPAT model, indicating that economic evolution and energy consumption positively influence CO2 releases and thereby contribute to environmental deterioration. The EKC model also confirmed these results for Turkiye, demonstrating an N-shaped EKC. Furthermore, under the DCC model, whereas improving energy efficiency can contribute to the reduction of CO2 releases, the evolution of the economy considerably boosts them. The nexus between renewable electricity, public debt, economic evolution, and CO2 releases during 1990-2020 had been investigated by Zeraibi et al. (2023) for emerging economies, including Turkiye; utilizing Augmented mean group (AMG), dynamic ordinary least square (DOLS), and fully modified ordinary least square (FMOLS) models; demonstaring that renewable electricity and public debt reduce CO2 releases. In these countries, a N-shaped nexus is evident between per capita CO2 releases and GDP per capita. In addition, the study identifies a two-way causal relationship between economic development and public debt, CO2 emissions and economic evolution, public debt and CO2 releases, and renewable

electricity and economic evolution. This calls for the promotion of renewable energy, boosting renewable electricity production, and attaining sustainable economic evolution through CO2 releases reductions. To explore how external debt affects the environment in Turkiye, Beşe & Friday (2022) utilized an autoregressive distributed lag model, with a particular focus on the nexus between CO2 releases per capita, GDP per capita, and per capita ecological footprint. A reversed U-shaped nexus between CO2 releases and external debt is evident, with no association between per capita ecological footprint and external debt. The outcomes revealed a bidirectional causal nexus between external debt and economic evolution, with a significant mien of economic evolution on the per capita ecological footprint in the long run. Additionally, causal nexus running from external debt to releases is evident; indorsing additional analysis to deeper understand the nexus between these variables. Magazzino et al. (2024) analyze the determinants of methane releases, a significant yet less researched greenhouse gas known to contribute to climate change; by investigating several factors includingdomestic credit to the private sector, total central government debt, GDP per capita, exports, total unemployment, urban population, renewable energy consumption, Voice and Accountability, and Gini Index; utilizing data from 192 countries from 1960 to 2022. Except the Gini Index, considerable miens of all variables across different distribution quantiles were recorded under the Panel Quantile Regression (PQR) estimates. According to the (SRT) model, methane releases are more likely to be reduced in poorer and resource-rich countries; indicating that public measures such as green education, digitalization, green financing, greater Voice and Accountability, and the promotion of green jobs could support these countries in effectively mitigating climate change and improving their efforts to reduce methane releases. Employing the ARDL model for the period 1975-2020, Çobanoğulları (2024) explores the nexus between economic evolution, CO2 releases, and health expenditures in Turkiye; showing that the analyzed variables are correlated both in the long- and short-run. The outcomes revealed that economic growth without renewable energy sources can increase CO2 releases, specially, a 1% economic evolution increment leads to a 0.553% (0.297%) upsurge in CO2 releases in the short run (long run); proposing transitioning to low-carbon technologies through improved energy efficiency and greater use of renewable energy to support sustainable economic evolution and alleviate the increase of emissions. Moreove, the study recommend that Turkey's health sector might improve through greater adoption of renewable energy or more efficient use of fossil fuels; based on the result indicated that a 1% increase in health expenditure leads to a 0.124% reduction in CO2 releases in the long run. Furthermore, the study warns that long-term population growth could adversely impact CO2 releases in Turkiye. Karahasan & Pinar (2021) utilize sulfur dioxide (SO2) measurements in Turkish provinces during 2004-2019 to validate the EKC hypothesis. Contrary to previous studies that use country-level data or disregard spatial dimensions, this paper applies spatial econometrics to account for spatial dependence and biases due to spatial spillovers. The evidence suggests a non-linear link between regional economic development and environmental deterioration, but instead of the expected inverted U-shaped EKC, there was a U-shaped relation between economic development and SO2 levels. The authors argue that these implications are robust even when regional spillovers are taken into account and indicate that Turkiye requires a revised post-2000 action plan to effectively tackle increasing environmental degradation. Daştan & Eygü (2023) examines the correlations between unemployment, income growth, and environmental impairment in Turkiye utilizing the Environmental Phillips Curve (EPC) and EKC frameworks. The study utilizes the (AARDL) model and examines annual data for the 1980-2018 period. To obtain robust results, the study includes six models in which natural resource rents, renewable energy consumption, foreign direct investment, financial development, and urbanization are included as control variables. The evidence confirms both the EPC and EKC hypotheses in the short and long run, demonstrating that natural resource rents raise the ecological footprint, while urbanization enhances environmental quality. Nevertheless, renewable energy, FDI, and financial development do not affect the environment substantially. Their analysis infers that without raising environmental awareness, integrating green energy technologies, expanding the use of renewable energy, and educating the labor force, increasing employment may hinder Turkiye's long-term development objectives. Degirmencioglu Aydin & Aydin (2023) investigated the main economic sectors' impact on environmental pollution in Turkiye during 1985-2017 per the EKC hypothesis. They also investigate the legal liabilities of companies concerning environmental pollution. Utilizing Fourier unit root and cointegration tests that account for structural breaks, they find that the EKC hypothesis holds only for construction companies that adversely affect

environmental quality. The authors propose specific legal regulations designed to curb environmental pollution in the construction industry; demonstarting the critical role of corporate companies' environmental consciousness in promoting sustainable economic growth. Including Turkiye, Cho et al. (2013) have proven the EKC hypothesis for methane (CH4) in 22 OECD nations; utilizing a fully modified ordinary least squares (OLS) approach, and using panel unit root and panel cointegration tests to inspect the associations between energy usage, CO2 releases, and GDP for these countries over the period from 1971 to 2000. Testing the EKC hypothesis for total greenhouse gases (GHGs) and other greenhouse gases such as nitrous oxide and methane, the study demonstres that energy use remains an essential factor in accounting for GHG emissions in OECD countries. By investigating the association between economic evolution and releases of eight air pollutants (CH4, CO2, NOx, N2O, SOx, NMVOC, CO, and NH3) over the period 1995-2009; Fujii and Managi (2015) revealed an N-shaped association for CH4 releases in 39 countries, including Turkiye. They weigh the EKC hypothesis against 16 individual industrial sectors and the total industrial sector, demonstrating that at least ten industries do not exhibit an EKC nexus for these pollutants. However, this linkage is observable at the country and total industrial sector levels. Key sectors that significantly affect the EKC nexus on a country and total industrial landscape include sectors that emit CO2, N2O, CO and NMVOCs. The results highlighted that EKC turning points and the association between economic development and pollutant emission trends differ by sector and pollutant, indicating the necessity for new environmental policies, such as a sectoral crediting mechanism that considers the specific characteristics of industrial emissions.

The existing literature review underlines the intricate and diverse nature of the nexus between economic evolution and environmental pollution under the EKC hypothesis. Whereas CO2 releases are extensively scrutinized due to their considerable mien on global warming, less attention was given to other greenhouse gases, such as methane, also having a prominent greenhouse bearing. The literature demonstrates that the EKC hypothesis is applicable to specific pollutants and contexts, however, it is not necessarily universal. For instance, economic evolution initially causes more environmental mutilation, which later improves, validating the EKC hypothesis for an ecological footprint (EF) and CO2, yet not consistently across all pollutants or sectors. Energy intensity, agricultural practices, public debt, renewable energy, and sector-specific characteristics are key factors determining these associations, underlining the critical need for specific environmental policies that consider these diverse factors, including promoting renewable energy, enhancing energy efficiency, and enforcing sector-specific regulations to mitigate environmental impacts while fostering sustainable economic evolution.

3. DATA AND METHODOLOGY

The principal intention of this study is to reinvest the EKC hypothesis utilizing CH4 releases as a proxy for environmental deterioration and considering the Agri-environmental indicators (IND), reconstructed via Principal Component Analysis (PCA) based on 13 variables outlined in Table 1.

Table 1: PCA Index Construction

Variable	Unit	Source
Total Fertilizers	Tons	OECD
Total Inorganic Fertilizers	Tons	OECD
Net input of manure	Tons	OECD
Livestock Manure Production	Tons	OECD
Total Cattle	Tons	OECD
Total Pigs	Tons	OECD
Total Sheep and Goats	Tons	OECD
Total Poultry	Tons	OECD
Total Other Livestock	Tons	OECD
Total Seeds and Planting Materials	Tons	OECD
Other Nutrient Inputs	Tons	OECD
Atmospheric deposition	Tons	OECD
Biological Fixation	Tons	OECD

To attain these objectives, a model is constructed using quarterly data covering the period from 2000Q1 to 202Q4, presented in Equation (1):

$$\ln MET_t = \beta_0 + \beta_1 \ln ECF_t + \beta_2 \ln \text{GDP} + \beta_3 \ln GFC_t + IND + \varepsilon_t \qquad (1)$$

In Equation (1), Where MET indicates methane gas releases measured as kt of CO2 equivalent, GDP denotes GDP in constant 2015 US$, ECF denotes Electricity from fossil fuels measured as TWh, GFC denotes the gross fixed capital formation in constant 2015 US$, t denotes the time, and ε_t symbolizes the error term. Barring the data of IND and that of ECF, which was obtained from Our World in Data, the data of the rest variables originates from the World Development Indicators (World Bank) for Turkiye. A standardized unit is required to account for distributional differences, as each of these variables is measured in different units. Consistent with prior research, all variables have been log-transformed to aid interpretation and allow for a more flexible analysis (Ehrlich, 1996; Shahbaz et al., 2020). Unit roots generally impede a proper understanding of the volatilities and stationarity characteristics of a series; posing a serious challenge in time series analysis. When a time series is non-stationary, statistical features such as mean and variance may change through time; thus complicating the modeling and forecasting processes. To deal with these challenges, various unit root tests have been developed, namely, Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests; to verify the stationary properties of time series data sets and evaluate whether differencing is needed to establish stationarity. Building on the original Dickey-Fuller test, the ADF test treats the autocorrelation problems in the error terms, by incorporating lagged differences of the dependent variable as additional regressors and imposing white noise residuals for a more accurate assessment of the stationarity of the series. However, building on the ADF test, the PP test incorporates more flexible assumptions regarding the error terms; by adjusting the test statistics to account for serial correlation and varying variance in the errors without adding lagged difference; thus becoming more robust when the error terms have weak interdependence and non-uniform distribution. Upon investigating the data set stationarity, the existence of a long-run correlation between the variables will be investigated utilizing an Autoregressive Distributed Lag (ARDL) bounds testing approach developed by Pesaran et al. (2001) and Pesaran and Shin (1999). This approach is particularily advantageous when the variables are integrated to different orders, i.e. I(0), I(1), or a combination of both, but not I(2). The bounds testing procedure entails estimating the ARDL model with ordinary least squares (OLS) for the selected lag orders, conducting an F-test for the joint significance of the lagged level variable coefficients, and comparing the calculated F-statistic to the critical value bounds provided by Pesaran et al. (2001). If a long-run association exists, an error correction model (ECM) is reckoned to capture the short-run dynamics and the pace of adjustment toward the long-run equilibrium.

4. FINDINGS AND DISCUSSION

4.1. Consequences of the Unit Root Tests

Table (2) presents the results of the unit root tests, demonstrating that lnMET, lnECF, lnGDP, and IND are non-stationary at their levels but become stationary after first differencing, however, lnGFC is stationary at its level I(0). The consequences of the unit root tests were represented considering the constant case.

Table 2: Consequences of Unit Root Test

Variables	PP		ADF		
	Level	First Difference	Level	First Difference	Decision
lnMET	-0.037 (0.952)	-5.405 (0.0000) ***	-0.438 (0.8965)	-2.849 (0.056) *	I(1)
lnECF	-1.698 (0.428)	-4.849 (0.0001) ***	-1.767 (0.3939)	-3.781 (0.005) ***	I(1)
lnGDP	-0.338 (0.914)	-4.476 (0.0005) ***	-1.611 (0.4724)	-4.456 (0.0005) ***	I(1)
lnGFC	-0.996 (0.752)	-4.717 (0.0002) ***	-2.692 (0.0800) *	-3.259 (0.020) **	I(0)
IND	1.298 (0.999)	-3.135 (0.0278) **	0.187 (0.9702)	-3.129 (0.028) **	I(1)

Source: Author's calculation, 2024

4.2. ARDL Long-Term and Short-Term Estimates

The bounds test for the ARDL model, which is suitable for variables integrated at either I(0) or I(1) order (Pesaran et al., 2001), was employed to investigate the potential long-term interactions among the analyzed variables. Based on the Akaike Information Criterion, the optimal lag length is 10 (AIC: -37.21755; SC: -29.21663), and the model's optimal lag selection is (10,10,10, 9,10). Table (3)

shows the conclusions of the bounds test, indicating that the F-statistic exceeds critical values at all levels, suggesting a long-term cointegration of the variables.

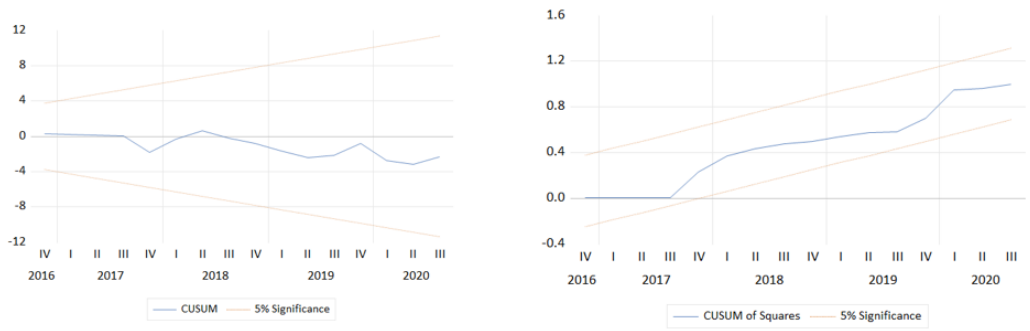
Table 3: Bounds Test Results

F-stat	10%level I(0)- I(1)	5%level I(0)- I(1)	1%level I(0)- I(1)
24.916	2.320-3.232	2.725- 3.718	3.608-4.860

Source: Author's calculation, 2024

Before examining the short- and long-term coefficients, it is crucial to evaluate the consequences of the diagnostic tests. The Serial Correlation LM test yielded an F-statistic of 0.400532, with a probability value of 0.5348, indicating no serial correlation and thus confirming the independence of error terms over subsequent periods. The Jarque-Bera test yielded an F-statistic of 1.185, with a probability value of 0.553, indicating that the null hypothesis of normality cannot be rejected. Moreover, the heteroskedasticity test produced an F-statistic of 0.523787, with a probability value of 0.4716, suggesting that the model does not exhibit heteroskedasticity. Additionally, the model remains stable over the specified period, confirmed by the CUSUM and CUSUMSQ graphs (Figure 1).

Figure 1: CUSUM and CUSUMsq Results



Source: Author's calculation, 2024

Labeling the cointegration nexus between the variables enables the analysis of the predicted long-term and short-term elasticities. Table (4) presents the consequences of both long and short-term cointegration.

Table 4: Long-Term and Short-Term ARDL Cointegration Results

Dependent Variable: MET, Model: ARDL (10,10,10,9,10)			
Variable	**Coefficient**	**t-statistics**	**Prop.**
Long Run			
lnECF	-0.052229	-1.101596	0.2844
lnGDP	0.669615	7.211075	0.0000
IND	-0.044408	-5.133194	0.0001
lnGFC	-0.247542	-7.811663	0.0000
Short Run			
Constant	-9.066167	-3.966686	0.0008
ΔlnMET(-1)	0.612382	10.13807	0.0000
ΔlnECF	0.103059	7.421055	0.0000
ΔlnGDP	5.100974	13.75306	0.0000
ΔIND	0.110946	10.04762	0.0000
ΔlnGFC	-1.331140	-13.68391	0.0000
ECM(-1)	-0.237205	-13.74194	0.0000

Source: Author's calculation, 2024

The results revealed a significant positive nexus between methane releases and economic evolution both in the long and the short term. Table 4 depicts that the long-term income elasticity

(0.67) is considerably lower than the short-term one (5.10). Accordingly, based on Narayan and Narayan's (2010) method, this implies that Turkiye has managed to reduce its methane releases over the long term while experiencing economic growth; and this conclusion aligned with that found by Shokoohi et al. (2022), Boluk & Karaman (2024), Ojaghlou et al. (2023), Karahasan & Pinar (2021), Cho et al. (2013) and Fujii and Managi (2015). The short-term positive nexus between the agri-environmental index (IND) and methane emissions (MET) indicates that initial efforts to improve agricultural productivity and environmental quality, such as increased fertilizer uses and higher livestock intensity, may temporarily raise emissions as a result of intensified practices and transitional adjustments. Over the long term, however, the negative correlation demonstrates that continuous improvements in the IND through sustainable practices, technological advances, better fertilizer and livestock management, and the adoption of supportive policies eventually lead to a reduction in methane releases. This is consistent with the (EKC) hypothesis, where initial economic and agricultural intensification raises emissions, but longer-term investments in sustainability and efficiency lead to environmental improvements and lower emissions. The short-run positive nexus recorded between electricity generated from fossil fuels (ECF) and methane releases (MET) indicates that rapid economic evolution and rising energy demand lead to increased reliance on fossil fuels, thereby causing more methane releases due to incomplete combustion and leakages during extraction and distribution. The adverse nexus in the long run, conversely, demonstrates that persistent economic development, technological advances, and regulatory measures have enabled the transition to cleaner energy sources including wind, solar, and hydropower. Through innovations and policy incentives, enhancements in energy efficiency reduce the overall demand for fossil fuel-based electricity. The adoption of renewable energy and better methane management practices could be promoted by the long-term regulatory interventions including carbon pricing and stricter emission standards. Jointly, these initiatives reduce reliance on fossil fuels and alleviate methane releases, mirroring a transition towards a more sustainable and environmentally friendly energy system; aligning with the EKC hypothesis, where initially economic activities boost releases, but sustained investments in cleaner technologies and efficiency eventually improve the environment.

The adverse nexus between gross fixed capital formation (GFC) and methane releases (MET), both in the short- and long-term, might be attributed to the immediate and lasting miens of capital investments on productivity and technology. Precisely, short-run investments in infrastructure, machinery, and technology facilitate the rapid adoption of more efficient and cleaner technologies, such as advanced equipment that reduces methane releases and better agricultural practices, including better fertilizer management. By optimizing resource use and waste management, these investments can lead to immediate reductions in methane emissions. These investments optimize resource use and waste management, resulting in immediate methane releases reductions. Over the longer term, persistent investments encourage technological innovation and progress, resulting in development and extensive adoption of cleaner, more efficient technologies and infrastructure, including renewable energy facilities and advanced waste management systems. These long-term investments promote economies of scale and advanced production processes, further decreasing methane releases. As well, long-term capital investments are frequently accompanied by supportive policies and regulations that foster sustainability and ensure continued methane release reductions.

5. CONCLUSIONS AND REMARKS

Employing Agri-environmental indicators (IND) reconstructed through Principal Component Analysis (PCA) based on 13 variables, this paper seeks to re-estimate the environmental Kuznets curve hypothesis in Turkiye from 2000Q1 to 2020Q4. Fallouts validate the EKC hypothesis, recommending the reassurance of more sustainable agricultural practices through subsidies for precision agriculture and enhanced manure management to mitigate short-term methane releases. To facilitate immediate and long-term decreases in emissions, it is essential to boost investments in clean technologies and infrastructure, including anaerobic digesters and renewable energy facilities. Moreover, energy efficiency and sustainability could be enhanced through strengthening regulatory measures, such as carbon pricing and stricter emission standards, coupled with supporting technological innovation and long-term capital investments. Furthermore, voluntary adoption of sustainable practices could be promoted through raising public awareness campaigns and education

programs. Monitoring and evaluation of policy impacts will ensure effectiveness, in addition, international cooperation will facilitate the sharing of best practices and technologies. To account for new environmental policies or technological advances, future studies could extend the timeframe or include more recent data. Moreover, incorporating alternative methods for constructing indicators or expanding the scope of variables could yield more comprehensive results. Furthermore, to provide more localized insights, sectoral and regional differences within Turkiye could be investigated or cross-country analyses could be compared. The role of global economic disruptions, such as the COVID-19 pandemic, and their impact on sustainable development pathways could be considered.

Ethics Statement: *In this study, no method requiring the permission of the "Ethics Committee" was used.*

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