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Do Agricultural Exports Mitigate the Impacts of Carbon Emissions in Türkiye?

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Agricultural exports influence ecological outcomes by promoting sustainable farming and eco-friendly technologies, aligning with international standards, and contributing to decarbonization and environmental sustainability. Türkiye has seen considerable growth in agricultural exports, but this rapid expansion raises concerns about its environmental consequences, especially regarding carbon emissions and overall ecological sustainability. This article investigates the impact of agricultural exports on environmental sustainability within the context of trade liberalization policies during Türkiye's export-oriented agricultural expansion from 1990 to 2015, utilizing the autoregressive distributed lag (ARDL) bounds testing approach. The findings demonstrate that agricultural exports significantly reduce environmental degradation over the long term. This is further validated by the Conditional Error Correction (CEC) model, which confirms that agricultural exports enhance ecological quality by lowering carbon emissions. Additionally, renewable energy consumption supports environmental sustainability by reducing carbon emissions. This research contributes to the existing body of knowledge by presenting empirical evidence on the interplay between agricultural exports and environmental sustainability in Türkiye. This article suggests that policymakers focus on an export-oriented agricultural extension strategy to address environmental challenges. Such a strategy should be aligned with the United Nations Sustainable Development Goals (SDGs) and integrate agricultural exports as a key component of Türkiye's long-term environmental sustainability plan.

Introduction

Numerous studies underscore the role of exports in enhancing productivity and contributing to economic growth (Krueger 1997; Balassa 1978). Export-led development is widely studied, particularly in developing economies that seek to capitalize on competitive advantages in agriculture. This relationship is particularly relevant for agricultural economies where export expansion directly impacts rural income levels, infrastructure, and production capacity (Helpman and Krugman 1985). Moreover, agriculture remains significant in developing economies because of its importance in feeding people, providing employment, and spurring agrarian manufacturing and industrialization. Agriculture's traditional role in development focused on its contributions to the economy, in that agriculture produces food for domestic consumption, supplies labour for industrial employment, provides input for agro-processing industries, enlarges market size for industrial output, contributes to foreign trade through exporting agricultural products, and finally makes up a substantial part of the national income (Gollin 2010; Pingali 2010; Timmer 2002; Mundlak 2001; Johnston and Mellor 1961).

Agricultural exports can influence environmental outcomes in various ways. Agricultural exports have the potential to significantly influence environmental outcomes by shaping production practices and resource use by driving the adoption of eco-friendly technologies and sustainable farming practices, particularly when exporters seek to meet stringent environmental standards in international markets. This can foster decarbonization and enhance ecological sustainability. However, the expansion of agricultural exports may also exert pressure on natural resources, leading to intensified land use, higher energy consumption, and increased greenhouse gas emissions if not managed sustainably. Balancing export growth with environmental considerations is therefore critical to achieving long-term sustainability. Export-driven agricultural modernization may encourage adopting eco-friendly practices and technologies, fostering decarbonization and environmental sustainability. Conversely, expanding production to meet export demand can lead to intensified land use, higher energy consumption, and greater greenhouse gas emissions (Balogh and Jámbor 2020; Hertel and de Lima 2020). Over the past four decades, agricultural lands in developed countries have decreased by approximately 10%, yet crop production has doubled, livestock production has grown, and emissions have declined by about 7%. In contrast, developing countries have seen a 13% expansion in agricultural lands, a doubling of crop production, a tripling of livestock production, and a 34% increase in total emissions (Bennetzen *et al.* 2016). These opposing outcomes underscore the importance of analysing the interaction between agricultural exports and environmental sustainability to understand their net impact.

Since the mid-1980s, the Turkish economy has experienced a significant structural transition from protectionist policies to neoliberal approaches, emphasizing export-led development processes in agriculture and manufacturing (Pamuk 2012; Arıcanlı and Rodrik 1990). This shift marked the gradual withdrawal of the state from the

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economic sphere, leading to the elimination of subsidies and a reduction in public investment in the agriculture sector (Boratav 2010) – the reform programme aimed to reduce the state's heavy agricultural involvement significantly. The programme's main components include eliminating input subsidies for credit and fertilizer, cutting back on state procurement activities, and privatizing state-owned economic enterprises. Based on the planted area, direct income support is a particularly notable and relatively new tool (Günçavdi *et al.* 2013; Çakmak 2003). As a reflection of this regime change in agriculture, various structural reforms and amendments were implemented to liberalize food markets aligned with the neoliberal restructuring of the economy, facilitated by the International Monetary Fund and the World Bank (Şenses 1996). Türkiye's World Trade Organization's commitments, the EU's Customs Union agreement, and other factors further liberalized the country's agricultural sector. Under the terms of the Customs Union agreement, Türkiye accepted all conditions, leading to the integration of its agriculture sector into the Common Agriculture Program (Kazgan 2009). New policy adjustments were subsequently implemented to increase overall productivity and reduce the role of the government in Turkish agriculture (Günçavdi *et al*. 2013).

The World Bank (2023) reported that agriculture accounted for 4% of the world's GDP, with some developing countries seeing it reach over 25%. Türkiye has a much larger agricultural sector than other OECD member countries, accounting for about 7% of total value added compared with 1.7% for the OECD area (OECD 2019a). Despite the sector's steadily declining GDP share, agriculture remains essential to Türkiye's manufacturing, tourism, employment, and exports, with a \$68 billion contribution to the country's GDP in 2020 (World Development Indicators). Figure 1 demonstrates developments in carbon intensity, renewable energy consumption, agriculture exports, and productivity in Türkiye, from 1990 to 2015, during the agricultural export expansion period thanks to trade liberalization in agrarian manufacturing. Aside from implementing structural adjustment programmes, Türkiye's agriculture has grown steadily thanks to the adaptation of sustainable land use, such as irrigated farming and fertilization. Intensive agricultural production and output growth have been accompanied by the introduction of differentiated agricultural support programmes, such as output support instruments involving deficiency payments that provide direct income support for farmers and input-based support programmes that include farm input subsidies such as support for fuel oil, fertilizer, and soil analysis (Bulut and Aslan 2022; Canbay 2021; Demirdöğen *et al.* 2016; Işık and Bilgin 2016). Notably, growing agricultural output for exports has been the major goal of agricultural policy. Agricultural exports rose and accounted for about 10% of total exports, which have become highly significant since a positive net agricultural trade balance helped to close Türkiye's overall trade deficit (OECD 2016). However, non-agricultural sectors have experienced more rapid growth than agriculture, resulting in a decline in agricultural land area. Additionally, the traditional structure of Turkish agriculture, characterized by small-scale farms and fragmented land ownership, hampers agricultural productivity and farmers' income. This structure increases input and

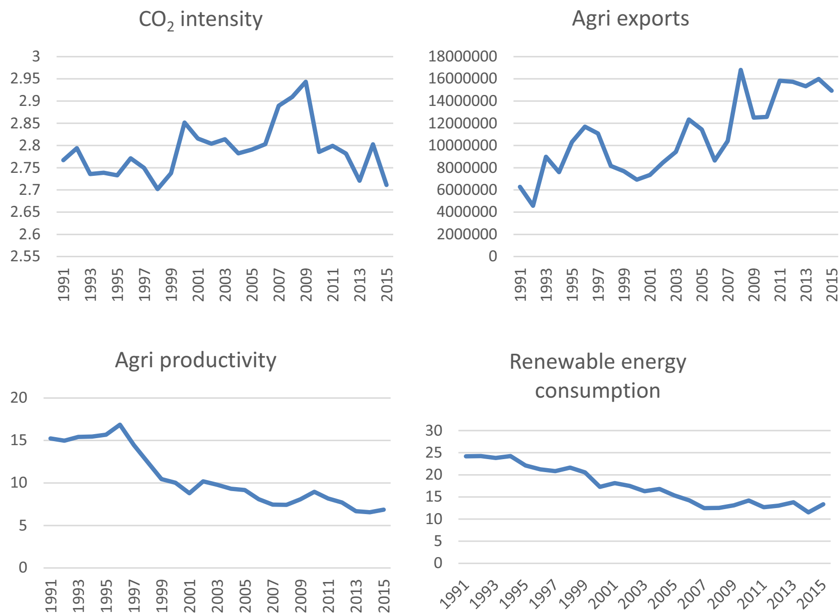

Figure 1. Developments in agriculture, carbon intensity, and renewable energy consumption in the period of agricultural export expansion.

production costs, employs a largely low-educated workforce, limits technological adaptation, and reduces the competitiveness of agricultural enterprises. Furthermore, family labour remains the primary source of farm labour, contributing to slow productivity growth in the sector (Akdemir *et al.* 2021; Ozgür 2021; Bayar 2018; Eruygur *et al.* 2016; Dudu *et al.* 2015; Kılıç and Kıymaz 2014).

Since 1990, total greenhouse gas emissions in Türkiye have risen significantly, marking the highest increase among OECD countries. Strong economic expansion, population growth, rising income levels, and dependence on a carbon-intensive energy mix have driven this growth. Between 1990–1992 and 2002–2004, agricultural greenhouse gas emissions in Türkiye declined by 21%, compared with a 43% increase in economy-wide emissions and a 7% reduction in agricultural emissions within the EU15. By 2002–2004, agriculture accounted for 6% of Türkiye's total emissions but represented just 1% of overall OECD agricultural emissions (OECD 2008). Agricultural emissions reduction was primarily due to decreased cattle, sheep and goat populations, which lowered methane emissions. However, this was partially offset by increased fertilizer use and crop production. However, from 2003–2005 to 2015, agricultural emissions experienced a 35% increase, driven by expanded agricultural production and rising on-farm energy consumption (OECD 2019b). On the other hand, while advancements in renewable energy adoption and energy efficiency have facilitated a partial decoupling of emissions from economic growth, the pace of this progress has lagged behind that of other member states (OECD 2016). The energy sector has been the main driver of this growth, accounting for 72%

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of the country's emissions. In 2018, industry process emissions accounted for 13% of emissions, agriculture for 12%, and waste management for 3% (IEA 2021). While per capita emissions remain below the OECD average, they are rising at a rapid pace, Türkiye ranked among the top ten carbon-emitting countries in the OECD in 2016, with a growing economy and expanding population. In 2017, coal constituted 33% of Türkiye's electricity generation, and coal-fired power is expected to continue playing a key role in the country's energy mix (OECD 2019a). The IEA (2016) also highlights that Türkiye has the largest coal power plant expansion within the OECD. While emissions from agriculture have risen more slowly than other sectors, they continue to increase. The growth in agricultural production has placed increasing pressure on the environment since 1990. Energy consumption on farms has risen, and greenhouse gas emissions from agriculture have also risen (OECD 2016).

Türkiye has witnessed considerable growth in agricultural exports, but this rapid expansion raises concerns about its environmental consequences, especially regarding carbon emissions and overall ecological sustainability. Türkiye is heavily dependent on imported energy, primarily from natural gas and oil, which account for more than 85% of the country's fossil fuel consumption (OECD 2019a). The IEA (2021) reported that the industrial sector emerged as the most significant energy consumer with 36% of the total final consumption in 2018, the transportation sector comes in second at 27%, followed by the residential sector at 20%, and the services sector, which includes fishing and agriculture, at 17%. Even though gas and oil are nearly entirely imported, all forms of renewable energy and about half of the coal are produced domestically. In 2019, 31% of the primary energy supply came from domestic sources. Half of the energy produced in Türkiye in 2017 came from fossil fuels, of which coal made up 43%, oil 7%, and natural gas 1%. Renewable energy sources such as hydro, solar, wind, geothermal, and biomass power accounted for most of the remainder. In the agricultural sector, energy consumption accounted for 4% of total final consumption in 2018. The main energy source was oil, which accounted for 65% of all agricultural energy usage.

In Türkiye, where energy-intensive agriculture and fossil fuel dependence remain prevalent, the interaction between agricultural exports and environmental sustainability presents a unique context for investigation. While existing literature has extensively explored agricultural exports' economic and social benefits, their environmental consequences remain underexplored. This gap is particularly pronounced regarding the potential to mitigate carbon emissions and enhance ecological sustainability. The primary motivation for this study lies in addressing this knowledge gap. As global environmental concerns intensify and Türkiye seeks to align its development strategies with the SDGs (United Nations 2015), understanding the role of agricultural exports in mitigating carbon emissions becomes imperative. This research posits that agricultural exports when strategically managed, can serve as a tool for achieving both development and ecological sustainability. Employing the autoregressive distributed lag (ARDL) bounds testing approach and the Conditional Error Correction (CEC) model, this study contributes to the literature by offering novel empirical evidence on the interaction between agricultural exports and the environment in Türkiye. It further recommends an export-oriented agricultural strategy that integrates ecological sustainability, providing valuable insights for policymakers seeking to balance economic and environmental objectives for sustainable development. This article's originality lies in its dual focus: first, it examines agricultural exports as a potential mitigator of carbon emissions, a perspective largely overlooked in previous research; second, it contextualizes the findings within Türkiye's unique environmental and policy landscape, offering actionable strategies for sustainable development.

In summary, agriculture still plays a vital role in the Turkish economy and supports employment in the labour market. Furthermore, Türkiye has a strong presence as a net exporter of agricultural products, and its trade in this sector has been steadily growing. A positive agricultural trade balance plays a crucial role in lowering Türkiye's overall trade deficit, underscoring the significant importance of agriculture and agrarian manufacturing. Therefore, the primary objective of this article is to investigate the impact of agricultural exports on environmental quality. The research seeks to answer how agricultural exports influence ecological sustainability, especially under the economic liberalization policy of Türkiye's agricultural output and export expansion from 1990 to 2015. This study also examines Türkiye's export-driven agricultural policies and the expansion of agricultural production concerning environmental sustainability, ensuring alignment with the SDGs. The ARDL method estimates the long-run relationships, focusing on how agricultural exports contribute to ecological sustainability and mitigate environmental degradation by reducing carbon emissions in Türkiye. For robustness, the CEC model is used to validate the findings. The existing trade–environment nexus literature neglects the role of agricultural exports when examining agriculture's impact on the environment in Türkiye. This study's exploratory approach makes a significant contribution by addressing this gap.

This article is organized as follows. The next section reviews the theoretical and empirical literature, and the third section presents the model and methodology for empirical analysis. The fourth section provides the results, and the final section concludes with recommendations for policy implementation.

Theoretical and Empirical Literature Review

The Environmental Kuznets Curve (EKC) hypothesis was the first to propose a theoretical link between trade and environmental outcomes, gaining significant attention in the early 1990s (Dean 1991; Grossman and Krueger 1991; Antweiler *et al*. 2001; Cole and Elliott 2003; Copeland and Scott 2004). Dean (1991) explored the effect of environmental regulations on trade patterns and the gains from trade, presenting a literature review to The World Bank highlighting the importance of environmental protection for sustainable development. The review discusses the negative effects of economic activities on the environment, emphasizing the need for a more sustainable development approach, advocated by the Brundtland

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Report (1987). Grossman and Krueger (1991) proposed a significant theoretical framework by examining the potential environmental impacts of NAFTA. Their influential paper concluded that trade liberalization could lead to Mexican specialization in sectors that cause below-average ecological damage, with pollution reduction potentially emerging as a secondary benefit of greater Mexican specialization and trade. Antweiler *et al.* (2001) contributed to the theoretical literature by developing a more systematic model that examines how openness to international markets influences pollution. Their model suggests that trade causes relatively small changes in pollution levels, primarily by altering the composition of national output. They concluded that freer trade generally appears to be beneficial for the environment. Cole and Elliott (2003) expanded on the Antweiler *et al.* model by providing a more detailed analysis of the factors influencing pollutants. Their study focused particularly on the trade-induced composition effect, which examines how changes in trade impact production structures and the resulting environmental outcomes. Their findings partly support the Antweiler *et al.* framework, confirming some of its conclusions while highlighting nuances in the relationship between trade openness and ecological impacts.

The empirical literature on the trade–environment nexus is extensive, yet the results remain mixed and uncertain. These discrepancies are largely due to differences in methodologies, datasets, and regional contexts, reflecting the complexity of the trade-environment connection. Trade liberalization can boost trade, but it may also increase greenhouse gas emissions and contribute to other environmental issues. However, free international trade can support climate mitigation efforts by lowering tariffs, aligning standards for ecological goods, and removing subsidies that distort fossil fuel and agricultural markets. Despite these synergies, reductions in average tariff levels have led to the trade of carbon-intensive products, such as fossil fuels and timber, more than eco-friendly goods (Balogh and Mizik 2021; Griffin *et al.* 2019).

In recent studies, Wang *et al.* (2022) examined the environmental efficiency of both developing and developed nations across Europe, the Americas, and the Asia-Pacific, exploring the effects of trade protection on a global scale under scenarios with and without trade. Their findings revealed that trade increased emissions in developing countries while reducing them in developed countries. However, the study also highlighted that environmental efficiency for both groups declined under the no-trade scenario, emphasizing the complexities of trade's ecological impacts and its role in global emission patterns. Wang and Wang (2021) explored the relationship between trade openness and carbon intensity across 104 countries and regions. Their analysis revealed significant asymmetric effects of trade openness on carbon intensity. Notably, the impact of trade openness was found to vary by income group: in high-income and lower-middle-income countries, trade openness decreased carbon intensity, while in upper-middle-income countries, it led to an increase in carbon intensity. These findings underscore the heterogeneous effects of trade policies on environmental outcomes, shaped by a nation's economic structure and income level. Dou *et al.* (2021) examined the environmental implications of trade openness within the China-Japan-South Korea Free Trade Agreement. Their findings highlighted that while trade openness tends to exacerbate the greenhouse effect, the signing of the agreement mitigates this impact, reducing the role of trade openness in driving carbon emissions; and imports contribute to higher carbon emissions, whereas exports are associated with significant reductions in a country's carbon emissions. This study underscores the nuanced environmental outcomes of trade agreements and the contrasting roles of imports and exports in shaping carbon footprints. Khan *et al.* (2020) found that, in the long run, imports contribute to an increase in consumption-based carbon emissions, while exports, advancements in environmental innovation, and renewable energy consumption contribute to mitigating emissions. These findings emphasize the importance of promoting exports, fostering ecological innovation, and investing in renewable energy sources to combat emissions effectively.

On the contrary, Udeagha and Breitenbach (2023) investigated the asymmetric relationship between trade openness and carbon emissions in the Southern African Development Community. Their findings present mixed evidence of asymmetry in the trade-emissions dynamic across member countries. In Botswana, Madagascar, Mozambique, and Tanzania, a long-run asymmetry was detected, while Comoros, Namibia, and South Africa showed both short- and long-run asymmetry. In contrast, Angola, the Democratic Republic of Congo, Lesotho, Malawi, Mauritius, Seychelles, Zambia, and Zimbabwe exhibited symmetric relationships and linear long-run connections between trade openness and carbon emissions. These results underscored the heterogeneous nature of the trade–environment nexus within this region, emphasizing the need for country-specific environmental and trade policies. Chen *et al.* (2021) analysed the relationship between trade openness and carbon emissions across 64 countries within the Belt and Road Initiative framework. Their empirical findings revealed that trade openness increases carbon emissions, indicating that greater trade activities are associated with higher emissions. This research pointed out the complexity of the trade–environment nexus and the need for tailored policy approaches in addressing trade-induced environmental challenges. Van Tran (2020) explored the interaction between trade openness and environmental pollutants by incorporating key determinants of environmental quality across 66 developing economies. The findings suggested that trade openness may adversely impact the environment, exacerbating pollution levels. Shahbaz *et al.* (2017) studied the connection between trade openness and carbon emissions across 105 countries categorized into high, middle, and low-income groups. Their findings demonstrated that trade openness negatively affects environmental quality across all income groups globally. However, the magnitude and nature of this impact vary significantly among these diverse country groups, reflecting differences in their economic structures and environmental policies. This study proposed the need for tailored strategies to address the environmental implications of trade openness in different economic contexts. On the other hand, Pham and Nguyen (2024) examined the impact of trade openness on environmental quality in 64 developing countries. They found no statistically significant evidence to suggest that trade openness affects environmental pollution in these nations.

Recent literature on the agricultural trade–environment nexus largely expresses concerns about the impacts of agricultural exports on the environment. Export-driven agricultural modernization may encourage adopting eco-friendly practices and technologies, fostering decarbonization and sustainability. Conversely, agricultural exports can influence environmental outcomes by expanding production to meet export demand leading to intensified land use, higher energy consumption, and greater greenhouse gas emissions. Saghaian *et al.* (2022) examined the impact of agricultural product exports on environmental quality across 23 developed and 43 developing countries. Their findings revealed that expanding agricultural exports in developing countries adversely affects ecological quality, as increased exports contribute to greenhouse gas emissions. In contrast, agricultural exports from developed countries reduce nitrous oxide emissions. Since agricultural exports are a key focus of export policy in many developing nations, policymakers should account for their environmental effects and work to raise farmers' awareness of the ecological consequences of their practices. Martinez-Melendez and Bennett (2016) found that the crop trade between the US and Mexico helped lower the environmental costs of agriculture in both countries. Conversely, Iriarte *et al.* (2014) identified on-farm production and overseas transportation as the primary contributors to the carbon footprint of banana production. They proposed mitigation and reduction strategies targeting these key emission sources to promote sustainable banana farming. Similarly, Schmitz *et al.* (2015) reveal that trade liberalization contributed to the expansion of deforestation in the Amazon. Chang *et al.* (2016) reported that international trade results in significant net economic losses for tropical countries due to the destruction of ecosystem services.

The literature on the agriculture–environment nexus in Türkiye has limited studies incorporating agricultural variables, neglecting the role of agricultural exports on environmental sustainability. Raihan and Tuspekova (2022) identified renewable energy consumption and agricultural productivity as factors that can reduce carbon emissions. Cetin *et al.* (2020) validated the EKC hypothesis, showing that agricultural value-added and land use reduce carbon emissions. Similarly, Doğan (2016) found that agricultural output lowers carbon emissions. In contrast, Yurtkuran (2021) highlighted that agriculture, renewable energy production, and globalization increase carbon emissions. Therefore, this research contributes to and fills the gap in exploring the impact of agricultural exports on environmental sustainability in Türkiye, which is disregarded in the literature.

Data, Model and Empirical Strategy

This article investigates the mitigating impact of agricultural exports on carbon emissions of Türkiye. The bounds test for the cointegration ARDL approach is adopted to seek the long-run relations between variables focusing on how

Table 1. Variables, definitions, units of measurement, and data sources.

Variable	Short definition	Units of measurement	Source
CO2	Carbon intensity	Kg per kg of oil equivalent energy use	WDI
APX	Agricultural products export	Value ($1000)	FAOSTAT
APV	Agricultural productivity	Agriculture, forestry, and fishing, value added (% of GDP)	WDI
RENE	Renewable energy consumption	% of total final energy consumption	WDI

Source: Author.

agricultural exports affect ecological sustainability and mitigate environmental degradation in reducing carbon emissions in the case of Türkiye. The time series characteristics of all variables are detected using ADF and PP unit root tests to avoid a spurious regression. Zivot-Andrews unit root tests with structural breaks are implemented on every individual series to see the effect of breaks on the series. After diagnostic tests, the ARDL bounds test for cointegration is followed by the CEC model to check robustness.

Data and Model Specification

For this study, the data are obtained from the World Development Indicators (WDI) and FAOSTAT datasets from 1990 to 2015 due to the availability of time series of the selected variables in the expanded agricultural exports of Türkiye.

Table 1 presents the definitions, units of measurement, and data sources of all the selected variables. This research considers carbon intensity as the dependent variable while agricultural product exports, agricultural productivity, and renewable energy consumption are explanatory variables. Carbon intensity refers to carbon dioxide emissions from solid fuel consumption, indicating mainly emissions from coal as an energy source as defined by the WDI database. Agricultural productivity denotes the value added by agriculture, forestry, and fishing as a percentage of GDP reflecting the contribution of agriculture to the GDP. Renewable energy consumption shows the share of renewable energy in total final energy consumption (WDI). Lastly, agricultural exports reveal the value of agricultural product exports as measured at $1000 (FAOSTAT).

To test the relationship between the dependent variable carbon emission and the explanatory variables – agricultural product export, renewable energy consumption, and agricultural productivity – the following model is specified:

$$CO2_t = f(APX_t, APV_t, RENE_t) \quad (1)$$

where $CO2$ = carbon emission; APX = agricultural exports; APV= agricultural productivity; $RENE$ = renewable energy consumption, t = time.

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Assuming that there is a linear relationship among variables, the model can be expressed as:

$$CO2_t = \varepsilon_0 + \varepsilon_1 APX_t + \varepsilon_2 APV_t + \varepsilon_3 RENE_t + v_t \quad (2)$$

where ε = long-run; v = error term.

To make it more linearized, the model is followed by a log-linear form expressed as:

$$LCO2_t = \alpha_0 + \varepsilon_1 LAPX_t + \varepsilon_2 LAPV_t + \varepsilon_3 LRENE_t + \varepsilon_t \quad (3)$$

where L = logarithmic form; α_0 = constant intercept; ε = white noise the error term; $_i$ (where i=1, 2, 3, 4) = long-run elasticity.

Empirical Strategy

Time series data can display different characteristics, including unit roots, instability, and susceptibility to structural changes and breaks (Pesaran and Timmermann 2005). However, estimating time series regression ignoring structural change and breaks, and the presence of unit roots can lead to spurious regression and meaningless results. The presence of a unit root in the regression is determined using the Dickey and Fuller (1979) ADF and Phillips and Perron (1988) PP tests in this paper. The tests assess the stationary properties of the data and determine if the variables are stationary at the level, first difference, or both. Nevertheless, it is important to acknowledge that the null hypothesis in these tests assumes a unit-root process with drift, which does not account for structural change or breaks, thus yielding misleading outcomes. Zivot and Andrews (1992) proposed an alternative trend-stationary process to remove this issue. Under the alternative hypothesis, this process permits an estimated break in the trend function. This article uses Zivot and Andrews' method to detect structural breaks in the data.

In addition, this article employs the bounds testing procedure within the ARDL cointegration approach developed by Pesaran *et al.* (2001). The two-step residual-based procedure for testing the null of no-cointegration by Engle and Granger (1987) and the system-based reduced rank regression approach by Johansen (1991) are alternatives to the ARDL bounds test for the cointegration procedure. The ARDL approach is applicable regardless of whether the underlying regressors are purely I(0), purely I(1), or mutually cointegrated. These alternatives are usually limited to situations where the underlying variables are integrated in order one. When the underlying regressors are I(1) or I(0), the ARDL method's reliability in small samples, as presented in this article, to estimate and test hypotheses on the long-run coefficients is one of its most notable strengths. Furthermore, this approach efficiently tackles issues related to endogeneity and auto-correlation (Pesaran and Shin 1999). Thus, the ARDL approach can effectively address omitted variable bias, mitigating the influence of unobserved factors that make the results unbiased.

The ARDL is utilized to identify the long-run and short-run associations between the variables *CO2* and *APX*, *APV*, and *RENE* as expressed in the following equation:

$$\Delta LCO2_t = \psi_0 + \psi_1 \sum_{i=1}^{k} \Delta LCO2_{t-1} + \psi_2 \sum_{i=1}^{k} \Delta LAPX_{t-1} + \psi_3 \sum_{i=1}^{k} \Delta LAPV_{t-1}$$

$$+ \psi_4 \sum_{i=1}^{k} \Delta LRENE_{t-1} + \Upsilon_1 LCO2_{t-1} + \Upsilon_2 LAPX_{t-1} + \Upsilon_3 LAPV_{t-1} + \Upsilon_4 LRENE_{t-1} + \varepsilon_t$$

where: 0 = constant; ψ = short-run; Υ = long-run; ε = residual term; Δ = difference operator; k = regressors; $\sum$= error correction dynamics; i = optimum lag length.

When the regressors are I(1), the ARDL procedure is valid; the selection of regressors should be based on computational convenience and small-sample properties (Pesaran and Shin 1999). The joint significance of the estimates of the lagged level of data can be tested for long-run relationships in the time series using the F-statistics test. The null hypothesis of no long-run association between variables is H0: $\beta_1 = \beta_2 = 0$, while the alternative hypothesis is H1: at least one $\beta_i \neq 0$. Two terminal critical values for the level of significance – one for the lower bound I(0) and the other for the upper bound I(1) – are compared with the computed F-statistic. The presence of cointegration is supported in the long run if the computed F-statistic is above the bound I(1), rejecting the null hypothesis that there is no cointegration. The null hypothesis is accepted and there is no long-term cointegration if it is less than the lower bound I(0). The outcome is unclear if it falls between I(0) and I(1).

Results

Descriptive Statistics and Correlations

Table 2 displays the descriptive statistics of the series. The results show that all series have low standard deviations, and skewness values are close to zero, indicating that all variables exhibit normal distribution characteristics. Table 3 presents the correlation results, indicating that all the variables are significantly correlated.

Results of the Stationary Tests

Using Vector Auto-Regressive (VAR) lag selection criteria, the proper lag length should be determined and chosen before performing unit root and ARDL cointegration tests. The Schwarz Criterion (SC) was consistently performed in this article, and Pesaran and Shin (1999) suggested that SC is a consistent model-selection criterion in a small size dataset, which is the case in this article. Therefore, this study uses the SC criteria to address the sample size limitation and chooses 1 lag to determine the best-fitting lag for the ARDL model, based on the VAR selection criteria results shown in Table 4.

All the series have a unit root with an intercept at the level, except *LCO2*, and a trend and intercept at the level, except *LAPX*, according to the results of the ADF and PP unit root tests in Table 5. All series that provide an intercept and a trend and intercept after differencing become stationary in both tests, proving that they are

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Table 2. Summary of statistics.

	LCO2	*LAPEX*	*LAPV*	*LRENE*
Mean	1.023494	16.15617	2.332698	2.841091
Median	1.023884	16.18883	2.257423	2.835158
Maximum	1.079538	16.63700	2.860842	3.199113
Minimum	0.971111	15.33607	1.880569	2.443216
Std. Dev.	0.023470	0.334545	0.320465	0.254882
Skewness	0.366558	−0.434770	0.303994	0.064288
Kurtosis	3.505488	2.588041	1.672523	1.531902
Jarque-Bera	0.859058	1.002963	2.309499	2.352830
Probability	0.650815	0.605633	0.315136	0.308382
Sum	26.61084	420.0605	60.65014	73.86837
Sum Sq. Dev.	0.013771	2.798014	2.567450	1.624123
Observations	26	26	26	26

Source: Author.

Table 3. Correlations.

	LCO2	*LAPEX*	*LAPV*	*LRENE*
LCO2	1	0.03632154937816957	−0.4857296035127465	−0.5587681620963767
LAPEX	0.03632154937816957	1	−0.5253062125117517	−0.6706146505936755
LAPV	−0.4857296035127465	−0.5253062125117517	1	0.9440173348167844
LRENE	−0.5587681620963767	−0.6706146505936755	0.9440173348167844	1

Source: Author.

integrated of order I(1). In both tests, *LCO2* and *LAPX* do not have a unit root with an intercept at the level of a trend and an intercept at the level, suggesting that they are both stationary and integrated of order I(0).

Applying unit root tests that account for structural breaks can be useful if a series has a unit root. The Zivot and Andrews test is employed in this work to determine the presence or absence of a structural break. The series has a unit root without breaks, according to the Zivot and Andrews test results, as shown in Table 6, at the level with intercept (model A), trend (model B), and intercept & trend (model C).

Results of the ARDL Bounds Test

According to the findings of the unit root tests, the series is stationary at mixed levels of either the level or first-order integration, I(0) or I(1), making the ARDL bounds test appropriate. The F-statistic is higher than the upper critical value, indicating the existence of a long-run relationship between the variables, the null hypothesis – which suggests there are no cointegration relationships among the regressors in the ARDL model – is rejected (Pesaran *et al.* 2001). The estimated F-statistic value (8.51) exceeds the upper limits at 10%, 5%, and 1% significance

Table 4. VAR lag selection.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	93.15339	NA	6.98e–09	–7.429450	–7.233107	–7.377360
1	147.0193	85.28761*	3.05e–10	–10.58494	–9.603226*	–10.32449
2	166.0852	23.83247	2.69e–10*	–10.84044*	–9.073355	–10.37163*

* indicates lag order selected by the criterion LR: sequential modified LR test statistic (each test at 5% level) FPE: Final prediction error AIC: Akaike information criterion SC: Schwarz information criterion HQ: Hannan-Quinn information criterion
Source: Author.

Table 5. Unit root tests without a structural break.

	Level		1st difference	
Variables & test type	Intercept	Trend & intercept	Intercept	Trend & intercept
ADF				
LCO2	–3.300***	–2.883	–5.904*	–5.904*
LAPX	–2.161	–4.679*	–6.820*	–6.577*
LAPV	–1.125	–2.040	–4.089*	–4.006***
LRENE	–1.111	–2.730	–6.383*	–6.226*
PP				
LCO2	–3.324***	–2.946	–6.257*	–6.726*
LAPX	–2.269	–4.679*	–10.276*	–9.472*
LAPV	–1.147	–2.249	–4.099*	–4.007***
LRENE	–1.036	–2.667	–6.846*	–6.865*

*and *** denote rejection of the null hypothesis at the 1% and 10% levels.
Source: Author.

Table 6. Zivot and Andrews unit root test with a break.

	Level		
	Intercept (Model A)	Trend (Model B)	Intercept & trend (Model C)
LCO2	–4.375*(2010)	–4.705*(2010)	–5.472***(2007)
LAPX	–5.383*(1999)	–4.217*(2002)	–6.005***(1998)
LAPV	–4.404***(1999)	–3.638***(2004)	–3.743(2002)
LRENE	–4.035*(2010)	–4.408*(2009)	–5.335*(2007)

*Denotes rejection of the null hypothesis at the 1% level.Break times are in parenthesis.
*** Denotes rejection of the null hypothesis at a 10% level.
Source: Author.

levels for both I(0) and I(1) orders of stationary and non-stationary bounds, as per the findings of the ARDL bounds test for cointegration shown in Table 7. The null hypothesis has been rejected, indicating a long-term cointegrating association between the variables.

Table 7. Results of ARDL bounds test.

Test statistic			Value			
F-statistic			8.51			
	10%		5%		1%	
Sample Size	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
30	2.676	3.586	3.272	4.306	4.614	5.966
Asymptotic	2.370	3.200	2.790	3.670	3.650	4.660

* I(0) and I(1) are respectively the stationary and non-stationary bounds.
Source: Author.

Table 8. Long-run results of the estimated ARDL

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LAPEX	–0.075496	0.024222	–3.116850	0.00
LAPV	0.120638	0.046064	2.618931	0.01
LRENE	–0.257843	0.071347	–3.613923	0.00

Source: Author.

The long-run findings of the ARDL model, shown in Table 8, indicate a significant negative association between carbon emissions and agricultural product exports, with a 1% rise in agricultural exports leading to a 0.08% reduction in emissions. Renewable energy consumption also demonstrates a significant negative effect, where a 1% increase results in a 0.26% decrease in emissions. Conversely, a 1% growth in agricultural productivity contributes to a 0.12% increase in carbon emissions.

In the short run, as outlined in Table 9, the ARDL model proves to be both significant and effective. Agricultural exports and renewable energy consumption are highly significant and inversely related to carbon emissions, with a 1% increase in each reducing carbon emissions by 0.04% and 0.24%, respectively. However, agricultural productivity is not significant in the short term.

Diagnostic Inspection

This study confirmed the reliability of the ARDL model using a range of diagnostic tests. The residuals are normally distributed, there is neither serial correlation nor heteroskedasticity, and the estimated model is also stable over time, according to the results of the diagnostic tests shown in Table 10 and Figure 2. This demonstrates that there have been no breaks or structural changes to the time series over the sample period. As a result, the study's models and parameters are trustworthy and consistent.

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Table 9. Short-run results of the estimated ARDL.

Variable	Coefficient	Std. error	t-statistic	Prob.
COINTEQ	–0.72	0.10	–7.14	0.00
DLAPX	–0.04	0.00	–4.51	0.00
DLAPV	0.03	0.02	1.61	0.12
DLRENE	–0.24	0.02	–9.08	0.00
R-squired	0.88	Mean dependent var		–0.00
Adj. *R*-squired	0.83	SD dependent var		0.02
SE of regression	0.00	Akaike info criterion		–6.44
Sum squared resid	0.00	Schwarz criterion		–6.05
Loglikelihood	85.37	Hannan–Quinn criteria		–6.34
Prob (F-statistic)	0.00	Durbin–Watson statistic		2.37

Source: Author.

Table 10. Results of diagnostic inspection tests.

Diagnostic tests	*p*-value
Heteroskedasticity: Breusch-Pagan-Godfrey	0.12
Breusch-Godfrey Serial Correlation LM Test	0.55
Jarque-Bera normality	0.79
Correlogram Q Statistics	0.64
CUSUM	Stable
CUSUM of squares	Stable

Source: Author.

Robustness Checking

Table 11 presents the results of the CEC model, which presents the robustness of the ARDL estimation demonstrating a negative and significant long-run relationship between carbon emissions and agricultural product export and confirming that agricultural exports mitigate carbon emissions.

Conclusions

Agricultural exports can influence environmental outcomes in different ways. Agricultural exports have the potential to significantly influence environmental outcomes by shaping production practices and resource use by driving the adoption of eco-friendly technologies and sustainable farming practices, particularly when exporters seek to meet stringent environmental standards in international markets. This can foster decarbonization and enhance ecological sustainability. This article examines the impact of agricultural exports on environmental sustainability in Türkiye, specifically focusing on the country's sustained growth in agricultural

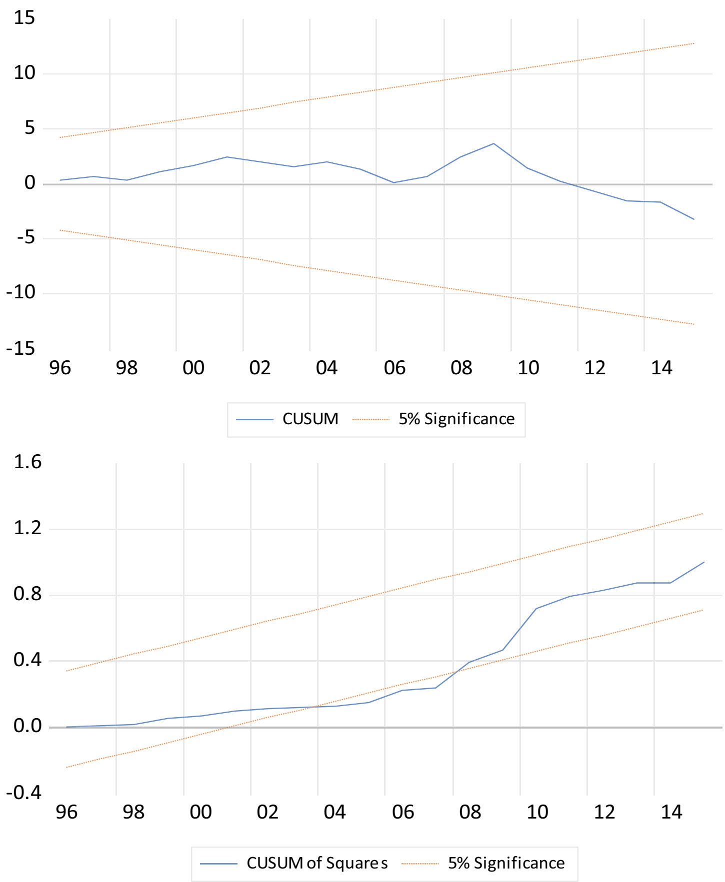

Figure 2. Stability of the model.
Source: Author.

production and exports from 1990 to 2015. It also explores the implications of export-driven agricultural policies within the context of environmental sustainability. The study employs the ARDL cointegration method bounds testing approach to address these objectives.

The findings indicate a strong negative correlation between carbon emissions and agricultural exports, where a 1% rise in agricultural exports results in a 0.08% decrease in carbon emissions. This underscores the substantial long-term role of agricultural exports in reducing environmental degradation. Specifically, Türkiye's agricultural exports lead to lower emissions from solid fossil fuels – such as coal, gas, and lignite – that are major sources of pollution in the country. This result underscores the considerable potential of agriculture to enhance environmental protection, particularly if Türkiye continues to scale up its agricultural production and exports. This growth has been supported by implementing various agricultural support schemes and input-based subsidies. Looking ahead, it is imperative to

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Table 11. Results of CEC regression

Variable	Coefficient	Std. Error	t-statistic	Prob.
LAPEX	–0.054483	0.013882	–3.924706	0.00
LAPV	0.087061	0.029400	2.961214	0.00
LRENE	–0.186077	0.044191	–4.210792	0.00

Source: Author.

prioritize the expansion of agricultural exports as a central objective of agricultural policy. Such a focus will sustain the sector's growth and further its role in promoting environmental sustainability. Although agricultural emissions have grown more modestly compared with other industries, they are expected to continue rising. Addressing these emissions is challenging owing to the limited availability of low-cost mitigation options. Promoting climate-friendly agriculture in Türkiye involves adopting precision farming, conservation practices, efficient irrigation, and organic farming to optimize resources and reduce emissions. Agroforestry and improved livestock management can enhance carbon sequestration and lower methane emissions, while drought-resistant crops strengthen climate resilience. Incentives such as subsidies and technical support can encourage sustainable practices, ensuring environmental and economic benefits. Some initiatives, such as payments for soil conservation and concessional loans for adopting sustainable agricultural practices, have been introduced to support farmers in improving the sustainability of their operations. Agricultural policies must increasingly integrate mitigation and adaptation strategies, promoting the adoption of cost-effective, climate-friendly measures. Adopting sustainable agricultural practices can significantly reduce greenhouse gas emissions while increasing farming systems' resilience to environmental deterioration's impacts.

Furthermore, this article finds that a 1% increase in renewable energy consumption results in a 0.26% reduction in carbon emissions. Therefore, renewable energy sources, including hydropower, geothermal, bioenergy, wind, and solar power, are to be promoted as viable alternatives to fossil fuels in agriculture and agricultural processing industries. This shift would further reduce carbon emissions and support efforts to combat environmental degradation. While renewables such as solar and wind energy have gained increased attention in recent years, their utilization remains relatively limited. Hydropower, a substantial renewable energy source, stands out as the most widely embraced alternative to fossil fuels. Türkiye's notable dependence on imported fossil fuels underscores the imperative for domestic energy production from renewable resources. Given Türkiye's heavy reliance on energy imports, which place a substantial strain on the economy and balance of payments, promoting renewable energy sources is a critical priority. Expanding these sustainable energy solutions can reduce import dependence, enhance energy security, and prevent rising environmental pollution. On the other hand, hydropower, generated by Hydropower Electricity Production Plants (HEPPs), is recognized as a clean energy source sensitive to climatic conditions. HEPPs boast the advantages of the lowest operating costs, the longest lifespan, and the highest efficiency compared with other energy generation methods. Prioritizing HEPPs as a domestic energy source presents an economical and strategic approach relative to other alternatives in Türkiye. Despite declining in fossil-based domestic energy production, HEPPs continue to play a crucial role in domestic electricity generation. Moreover, the increasing adoption of clean renewable energies such as solar, wind, and geothermal holds promise for implementing a diversified and environmentally friendly sustainable energy production strategy in Türkiye.

The findings of this study offer valuable recommendations for policymakers aiming to develop a comprehensive agricultural extension and export strategy for the Turkish economy to reduce carbon emissions and focus on the mitigation role of agriculture in environmental degradation. This strategy must include support for expanding agricultural output and boosting agricultural exports. Several strategic agroecological interventions have been proposed to tackle the challenges confronting Türkiye's agricultural sector. First, policies should be implemented to consolidate fragmented and scattered land holdings, creating larger, more efficient farm units that benefit from economies of scale and enhanced productivity. Implementing advanced agricultural technologies through subsidies, training programmes, and research partnerships is crucial for modernizing the sector. Investment in education and vocational training for farmers will improve management practices and facilitate the adoption of new technologies. Export-led agricultural modernization can promote environmentally friendly practices and technologies, support decarbonization, and enhance sustainability. Second, pursuing support programmes for small-scale farmers, including access to financial services and market information, is essential to overcoming barriers and improving productivity. Encouraging the development of agribusinesses and rural enterprises can add value to agricultural products and stimulate economic activity in rural areas. Third, enhancing labour productivity through mechanization and modern farming techniques, alongside policy and institutional reforms to address land tenure and infrastructure issues, is vital. Emphasizing sustainable agricultural practices and investing in rural infrastructure will further bolster productivity and competitiveness. Enhancing agricultural cooperatives can increase small-scale farmers' access to resources and strengthen their bargaining power. These comprehensive measures can collectively address the existing problems in Turkish agriculture and promote a more productive and sustainable sector. Finally, this strategy should emphasize promoting renewable energy consumption to address environmental degradation, aligning with SDGs. Türkiye should continue integrating the SDGs into its National Adaptation Strategy and Action Plan, ensuring progress toward the 2030 and 2050 targets for transition to a low-carbon economy.

While this study contributes valuable insights to the literature, it is important to acknowledge certain limitations that may impact the generalizability and reproducibility of the findings. Two primary limitations are the sample size and lack of prior research. First, the relatively small sample size may restrict the generalizability of the results. To mitigate this limitation, future research should include larger, more diverse samples to enhance the reliability and generalizability of the findings. Second, the lack of prior research presents challenges in establishing a robust theoretical framework. The limited body of existing literature may hinder the comparison of the current findings with those from related studies, thus complicating the interpretation of results. However, this limitation also highlights the novelty of the research and underscores the importance of further investigation. The exploratory nature of this study represents a crucial step toward addressing a significant gap in the literature. In conclusion, while these limitations are inherent to the current study, they do not diminish the importance of the findings.

Data Availability

These data were obtained from the FAOSTAT, https://www.fao.org/faostat/en/#data; World Bank, https://databank.worldbank.org/source/world-development-indicators

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