ÇOMÜ Zir. Fak. Derg. (COMU J. Agric. Fac.)
2025: 13(2): 390-407
ISSN: 2147–8384 / e-ISSN: 2564–6826
doi: 10.33202/comuagri.1724967

OPEN ACCESS

Research Article

Agricultural Greenhouse Gas Emissions – Economic Growth Relationship in Türkiye: Are Agricultural Farmgate Emissions a Major Factor?

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Received Date: 23.06.2025 Accepted Date: 18.11.2025

Abstract

Although Türkiye's agricultural sector has largely complied with the European Union (EU) acquis, it has not yet developed a clear strategy for greenhouse gas (GHG) mitigation or climate adaptation. In contrast, the EU's strict climate policies have triggered farmer protests, reflecting the tension between policy ambition and sectoral readiness. This paper investigates the relationship between farmgate GHG emissions and economic growth in Türkiye. Using data from 1990–2022, we apply a Vector Autoregressive (VAR) model to test causal linkages among GDP, agricultural emissions, and non-agricultural emissions. The results show no statistically significant causality between GDP and either agricultural or non-agricultural emissions. However, given Türkiye's trajectory as an emerging economy aligning with the EU, policy implications can be distinguished along supply- and demand-side dimensions. Supply-side mitigation such as changing traditional farming practices may face resistance and require long adaptation periods in rural areas. Conversely, demand-side strategies, including dietary shifts, innovations in food processing, and consumer-driven transformations, appear more feasible in the short term. Over time, these changes may gradually lead to mitigation within farmgate practices. The main contribution of this study is to highlight demand-side mitigation as a more realistic entry point for Türkiye's climate policy in agriculture, offering a pragmatic roadmap for aligning economic growth with emission reduction goals.

Keywords: Vector Autoregressif Model; Time Series; Agricultural Emissions; Sustainable Economic Growth; Türkiye

Türkiye'de Tarımsal Sera Gazı Emisyonları ve Ekonomik Büyüme Arasındaki Etkileşim: Tarımsal Üretici Emisyonları Majör Bir Faktör mü?

Öz

Türkiye'de tarım sektörü, AB'ye uyum sürecinde birçok kriteri yerine getirse de sera gazı emisyonlarının azaltımı (mitigation) veya iklim değişikliğine uyum (adaptation) için net bir strateji geliştirmemiştir. Oysa AB'de çiftçi protestolarının temel nedenlerinden biri, liderlerin iklim politikalarındaki katı tutumudur. Bu çalışma, Türkiye'de tarımsal sera gazı emisyonlarının (farmgate emissions) ekonomik büyüme ile ilişkisini incelemektedir. Analizde 1990–2022 dönemi verileri kullanılmış ve tarım dışı emisyonlar ile tarımsal emisyonların GSYH ile nedensellik ilişkisi Vector Autoregresif (VAR) Model aracılığıyla test edilmiştir. Bulgular, GSYH, tarım dışı emisyonlar ve tarımsal emisyonlar arasında istatistiksel olarak anlamlı bir nedensellik bulunmadığını göstermektedir. Ancak Türkiye'nin AB'ye uyum süreci ve benzeri gelişmekte olan ekonomilerin izlediği yol dikkate alındığında, politika seçeneklerinin arz ve talep yönlü olarak ayrıştırılması gereklidir. Arz yönlü stratejiler, kırsal alanda yüzyıllardır süregelen tarım teknikleri nedeniyle kısa vadede sınırlı olabilir. Buna karşılık, talep yönlü politikalar—diyet değişimi, işleme sanayinde teknolojik dönüşüm ve tüketici tercihlerinde farklılaşma daha uygulanabilir görünmektedir. Çalışmanın temel katkısı, Türkiye'de tarımsal emisyon azaltım politikalarının başlangıç noktası olarak talep yönlü stratejilerin önceliklendirilmesi gerektiğini göstermesidir. Bu sonuçlar, iklim değişikliğiyle mücadelede daha gerçekçi ve uygulanabilir bir yol haritası önermektedir.

Anahtar Kelimeler: Vektör Otoregressif Model; Zaman Serisi; Tarımsal Emisyonlar; Sürdürülebilir Ekonomik Büyüme; Türkiye

Introduction

The Common Agricultural Policy (CAP) of the European Union (EU), after 67 years marked by successes, is currently at the center of the most controversial protests. It would be unfair to deem the policies that have created a modernized agricultural geography, constituting 13.2% of the world's basic agricultural product value and holding 10% of international agricultural trade, as unsuccessful. However, unexpected changes in the global economic, political, and environmental landscape, often referred to as global shocks, have prompted the countries that have developed these strong policies to reconsider their approaches. The discontinuity in production during the COVID-19 pandemic, energy bottlenecks, climate crisis, the Russia-Ukraine conflict, turmoil in the Middle East, and spikes in oil prices have impacted, and continue to impact, not only all countries but also EU member states. In addition to these factors, the externalities created by their highly competitive power in different countries have led to a perceived need for reform due to both environmental and socio-economic reasons(Coderoni and Esposti, 2018a).

The exceeding or impending surpassing of the ecological damage threshold in certain regions due to intensive agriculture has led to discomfort among many European Union member states, thereby pioneering the emergence of the sustainability concept. Another issue of great concern to EU countries is the setting of global targets by the UN regarding sustainable environmental policies. Academic circles and the world environment-protection-public opinion are aware of the 13th Sustainable Development Goal (SDGs) by the United Nations (UN). In line with this goal, world countries should achieve a 45% reduction in global net carbon emissions from 2010 to 2030 to effectively mitigate global warming and limit it to a 1.5 $^{\circ}$C increase. Additionally, the SDGs set a target of achieving global net zero carbon emissions by approximately 2050 (United Nations, 2024). As a result, it was expected that environmentally friendly policies would come to the forefront in the EU before the rest of the world. In short, the EU does not want to be one of the geographies that disrupts the global carbon balance.

The goal of achieving sustainable production, amidst the external challenges mentioned above, has exacerbated the feeling of more severe structural issues. The increase in constraints within the traditional system that the agricultural sector has been accustomed to for years has led to difficulties in production and trade, resulting in farmer protests. EU countries have been in a more advantageous position compared to almost all farmers worldwide for the past 67 years, thanks to the common funds they have obtained. The daily agenda of EU farmers and policymakers revolved around the use of agricultural chemicals, combating diseases, achieving high yields, and responding to increased global competition. Research indicates that EU agricultural lands are heavily depleted, and it is inevitable that environmental issues will arise in the near future under these intensive conditions. While some studies emphasize the shifting of agricultural activities to less developed regions (such as the 10+2 countries), implementing revolutionary actions is not an easy task (Gurlük, 2009).

The key concerns of farmers who are in the grip of the above-mentioned problems experienced in their countries in the 12 EU members, where the demonstrations are violent, are classified around biodiversity/conservation, climate/emission, and others. The following issues were discussed: the stringency of the EU nature restoration law rules, EU trade agreements that lead to cheap imports, increasing EU COP support for farmers, improving farmgate prices for farmers, dropping fuel subsidies, pesticide use restrictions, compensating farmers affected by extreme weather events, improving infrastructure investments to protect against extreme weather events, reintroducing income tax breaks, no need to reduce nitrogen emissions, the requirement for slow farm subsidy payments, and more aid for sectors hit by the ongoing drought (Carbonbrief, 2024). In summary, stakeholders in the EU agricultural sector acknowledge the problems, but they want adaptation and mitigation policies to be implemented rapidly in order to overcome them.

While Türkiye, as a developing country, competes with European Union countries in terms of agricultural trade, it has just began to focus the issues discussed by the EU, such as climate change, biodiversity, and precision farming systems. The reason why farmer protests have not yet reached Türkiye is closely related to the fact that it has not received any EU CAP funding for 67 years, as Turkish farmers have been deprived of these supports. The use of agricultural chemicals in many production areas has not reached the desired level yet. Turkish agriculture does not currently practice intensive agriculture to the same extent as the EU. Since populist policies applied to agricultural inputs do not create changes in agricultural infrastructure policies, there is currently no restriction on Turkish farmers. Turkish farmers are therefore only watching these protests. The large amounts of agricultural input subsidies received by large-scale enterprises do not yet create an uncomfortable political environment for Turkish farmers. It can be argued that unlike EU farmers, the weak culture of unionization, cooperation, and collective action among farmers also plays a role at this point. Nevertheless, in the last decade Türkiye has experienced a significant rise in pesticide use and other input-dependent practices, leading to a measurable increase in its greenhouse gas (GHG) emissions from agriculture. This raises questions about the country's long-term sustainability trajectory, especially in relation to its trade integration with the EU.

Despite this growing concern, existing literature has rarely isolated "farmgate emissions" from total agricultural or economy-wide emissions in Türkiye. Most studies aggregate agricultural emissions without distinguishing between emissions arising directly from primary production (farm-level) and those generated downstream through processing, transportation, and consumption. This lack of disaggregation obscures the specific role of farmgate practices in shaping the country's emission profile. Thus, a clear research gap exists: the need to explicitly analyze the relationship between farmgate emissions and economic growth in Türkiye, and to contrast it with non-agricultural emission dynamics.

Many developed countries, particularly the EU, continue to implement cheaper climate change adaptation policies and prepare to implement more expensive mitigation policies (Baldock et al., 2007). In this context, the European Green Deal declared by the EU in December 2019 was actually a justification for the farmer demonstrations. This series of climate change mitigation strategies is not only the EU's strategy to achieve the Paris Climate Agreement goals, but also heralds a total economic and social transformation (EDF, 2024). The Green Deal aims to reduce the climate footprint in all sectors from industry to agriculture, from construction to transportation, to act in line with sustainability principles, to separate the circular economy and resource use from economic growth, to eliminate damage to the environment and nature, to protect and restore biodiversity, to renewable energy. and investing in carbon capture and storage technologies. As the EU steps into this new adventure, it wants to be the pioneer of a new transformation that will affect the whole world. As the world's leading trade actor along with the USA and China, the EU aims to spread the transformation throughout the world through its commercial, economic and political relations.

Green deal strategies envisaged in all sectors have also changed the objectives of EU Common Agricultural Policy. While the EU Council included 3 market-oriented objectives among the new CAP objectives announced under 9 headings, the remaining 6 objectives are related to natural resource use and efforts to prevent climate change. Ensuring farm income, increasing competitiveness, rebalancing power in food chain have been determined as more market-oriented strategies. Climate change action, environmental care, preserving landscape and biodiversity, supporting generational renewal, creating vibrant rural areas and protecting food and health quality can be considered environmentally friendly strategies (Smol, 2022; Szpilko and Ejdys, 2022)

Transition countries to market economy or developing countries may experience similar issues with globalization (Kyriazil and Miro, 2023). Indeed, in a study conducted on emerging economies (Brazil, Russia, India, China, and South Africa, BRICS) using the ARDL bound test between 1971 and 2013, the causal relationship between agricultural production and carbon dioxide emissions was examined, disaggregated into crop production and livestock. Empirical results suggest that a 1% increase in economic growth, crop production, and livestock production will lead to a proportional increase in carbon dioxide emissions by 17%, 28%, and 28% respectively, while a 1% increase in energy consumption (Appiah et al., 2018). Countries face many challenges while striving to ensure food security and reduce the proportional share of food expenditures within income. The sector's internal challenges and energy bottlenecks caused by globalization-driven outward policies, along with global environmental issues, are significant external problems. In developing countries like Türkiye, alongside all these unresolved issues, the design of mitigation policies will inevitably become essential in the near future. Focusing on farmgate emissions therefore allows us to address both a conceptual and policy gap: by examining the emissions at their source in Türkiye's agricultural system, we can better evaluate whether structural changes in farming practices or demand-side strategies (such as dietary shifts) are more effective entry points for mitigation.

The aim of this article is to examine the relationship between Türkiye's agricultural greenhouse gas emissions and Gross Domestic Product(GDP) and to determine the strategies the country should follow to avoid being affected by stringent environmental policies in the EU, while experiencing a harvest season free from agricultural protests.

The literature on the subject has predominantly focused on the relationships between total emissions, agricultural emissions, energy use, and GDP. Sarpong et al., 2023, studied with time series analysis in seven-emerging-countries (E7), China, Türkiye, India, Russia, Brazil, Indonesia, and Mexico, and state that environmental tax, renewable energy, and access to clean fuels and technologies for food processing decrease carbon emission for those economies. On the other hand, urbanization and population growth enhance emissions for the E7 economies. Muhadinovic et al. (2021) analyzed the sectoral differences in greenhouse gas emissions in Montenegro and demonstrated that the agricultural sector contributed to GDP over a 24-month period. Han et al. 2018, argue that bidirectional short-run causality between CO_2 emissions and GDP are the signal to develop a low-carbon economy needed to address the dilemma between economic development and carbon emissions. Nguyen et al. (2020) states that the increases in income and economic integration are the major contributors to higher GHG emissions from agriculture in the short run. They reported that the increases in income, agriculture value added, and energy consumption are the major drivers of agricultural emissions in the long run. Haider et al. (2020) analyzed the relationship between N_2O emissions and per capita GDP within the scope of their study on the Environmental Kuznets Curve analysis. If countries wish to reduce their N_2O emissions or agricultural N_2O emissions, they should reduce the use of agricultural land. At this point, it can be said that farmgate emissions show a high correlation with N_2O contributions. In the study, no difference was found between the first group of countries, including Türkiye, and the second group of less developed countries in the comparison. There is a substantial literature on reducing or adapting to agricultural emissions. A common point where researchers converge is that reducing agricultural emissions cannot be one-sided. In this context, the importance of supply and demand-oriented strategies has also been emphasized (Poore and Nemecek, 2018). Researchers, aware of the difficulties in many developing (and even developed) countries, have also suggested following a roadmap with different stages. The importance of this roadmap, which encompasses both behavioral and production changes, has been emphasized: (1) for greater mitigation potential; (2) for exploration of mitigation and adaptation co-benefits, synergies or trade-offs; (3) to identify clear research gaps; and (4) to integrate options that fall both inside and outside of agricultural production (e.g., dietary choices, food waste)(Niles et al., 2017; Rosenzweig et al., 2020).

In the current paper, it is assumed that agricultural greenhouse gas emissions and non-agricultural greenhouse gas emissions contribute to GDP. If there were no economic activities, then there would be no greenhouse gases emitted into the atmosphere (Harris, 2002). However, with advancing technology and increasing levels of education and awareness, the emergence of more efficient economies is possible (Gurluk, 2009). All these factors will have a reducing effect on greenhouse gas emissions into the atmosphere. The advanced economies of countries, along with their citizens and policymakers, are leading proponents of the concept of sustainable development today. The agricultural sector is responsible for approximately 10-12% of greenhouse gas emissions in the atmosphere, primarily from agricultural production. With the addition of processed food products and transportation activities, the greenhouse gas impact of basic agricultural products and the sector is steadily increasing. Countries that are increasingly aware and responsible and aim to adapt to international climate change are making efforts to take measures in the agriculture sector, which is closely intertwined with nature. The methodology used in the study is Vector Autoregressive model (VAR), which is an econometric time series analysis used to better understand the relationship between the agricultural production system implemented in Türkiye and GDP. The model was used to investigate the causal relationship between agricultural greenhouse gas emissions and GDP. The study interrogates two hypotheses in a manner that contributes to the existing literature. These hypotheses inquire whether the source of agricultural emissions is farmgate emissions and whether there is a relationship between non-agricultural emissions and GDP. Our predictions suggest that in Türkiye, the agricultural sector contributes more to GHG emissions through areas such as agri-business and transportation rather than agricultural production itself, and that farmgate emissions do not contribute to GHG emissions production. Food policy studies have been conducted on the separate analysis of agricultural greenhouse gas emissions(Garvey et al., 2021; Garvey et al., 2022; Stewart et al., 2023a). The impact of various dietary practices on GHG emissions is investigated to demonstrate that although the food system accounts for 23-42% of emissions (Stewart et al., 2023a). Significant portion of these emissions occurs in the stages after the primary agricultural product is produced. The study's focus on disaggregating agricultural and non-agricultural emission contributions aims to better illustrate the distinction between agricultural production and consumption and to fill a gap in the literature. The expectation regarding the second hypothesis is the presence of a relationship between non-agricultural emissions and GDP. In that case, the specified hypotheses are as follows:

H_1: There is a relationship between farmgate GHG emissions and GDP

H_2: There is a relationship between non-agricultural emissions and GDP

Material and Method

The material of the research consists of time series data obtained from FAOSTAT, World Bank (WB) and Turkish Statistical Institute. Uzel et al. (2022), methodology was used to calculate Green House Gases (GHG) emissions from crop production. GHG emissions' CO_2 equivalent arising from agricultural production was calculated by conversion factors. GHG gases arising from crop production contains emissions from synthetic fertilizers which consist of nitrous oxide gas from synthetic nitrogen additions to cultivated soils. The data calculations are from IPCC, and is available at FAO (IPCC, 2006; FAO, 2019). Climate scientists, after seve-ral experiments, calculated in the mid-2000s that dirt dwellers spew about one kilogram of the greenhouse gas for every 100 kg of fertilizer. In addition, it is stated that the emis-sions will be linearly doubling when the uses of fertilizers are increased (Sciencenews, 2019). GHG emis-sions from crop residues consist of direct and indirect nitrous oxide emissions from nit-rogen in crop and forage/pasture renewal residues left on agricultural fields by farmers. GHG emissions from burning crop residues consist of methane and nitrous oxides. The nitrous oxide gases occur by the combustion of a percentage of crop residues burnt on site. The mass of fuel available for burning should be estimated taking into account the fractions removed before burning due to animal consumption, decay in the field, and use in other sectors (biofuel, domestic livestock feed, building materials, etc.). GHG emissions from burning as cultivation of organic soils technically consist of both CO_2 and nitrous oxide(N_2O). Drainage and cultivation of peat soils increase soil aeration and reverse the carbon flux into a net CO_2 emission into the atmosphere. Farmed organic soils are a large source of both CO_2 and nitrous oxide emission, due to the net degradation (oxidation) of the parent material (Klemedtsson, 1997).

GHG emissions arising from livestock contains the GHG emissions originat-ing from livestock rearing. The livestock data disseminates total methane (CH_4) and ni-trous oxide (N_2O) emissions originating from livestock-related processes. Detailed emis-sions are also disseminated from "enteric fermentation" which is the CH_4 emissions produced from enteric fermentation processes in the digestive systems of ruminants and to a lesser extent of non-ruminants, "manure left on pasture" which is the N_2O emissions originated from the nitrogen in manure left by grazing livestock on pasture and "manure management" which is the CH_4 and N_2O emissions originating from aerobic and anaerobic processes of manure decomposition.

One of the most significant errors in emission calculations is conducting a sectoral calculation that encompasses the entire agricultural industry instead of focusing solely on farmgate emissions. Research conducted at the agricultural industry level and research conducted at the farm level should be analyzed and interpreted differently from each other. A significant portion of emissions in the agricultural industry stems from production-independent food chain relationships such as transportation, processing, and catering services. The role of farmers revolves around producing primary agricul-tural products and deciding whether to implement emission regulatory measures up to this point. Therefore, farmgate analyses provide more useful insights into the rela-tionships between the agricultural sector and GDP. Crop production and livestock emis-sions were combined to obtain agricultural farmgate emissions data. All data has been converted to CO_2 equivalent. Non-agricultural emissions have been calculated by sub-tracting farmgate emissions from the total emission quantity. GDP data has been in-cluded in the analysis, taking into account the constant USD values declared by the World Bank.

When examining the historical evolution of GDP and the agricultur-al-non-agricultural emissions under investigation, it will become apparent whether the series is driven by its own past values and/or random shocks. While GDP exhibits be-havioral characteristics, emission production demonstrates distinct features. Tradition-ally, when working with cross-sectional data in econometrics, reaching a common solu-tion through simultaneous equation models is possible. However, the necessity of find-ing a common variable for solving equation systems does not always make it feasible to conduct many analyses. In VAR models, this is not an issue, as it enables multivariate analyses within the framework of time series econometrics.

The series must be stationary so that econometrically significant relationships between variables in time series analyses could be obtained. The most significant as-sumption in a regression analysis including time series data is that the time series handled is stationary. Regarding general terms, if its mean value and variance are constant in time and the covariance value between two periods depends not on the main period when this covariance is calculated but on the distance between the two periods, this time series is stationary (Sevuktekin and Cinar, 2017). A time series with these characteristics is known as weak sta-tionary. If not the first two moments of a time series (that is, mean and variance) do not show a change in time, but all moments do; the series is definitely stationary. The difference is taken if the variables are non-stationary, and the series are rendered stationary. As the co-transformation data between data disappears through taking the difference, inferences are made through action-reaction functions and causality analyses rather than evaluations in the classical regression analysis. Although various methods have been developed to understand the stationarity of series, the Augmented Dickey-Fuller (ADF) and the Phillips-Perron tests stand out with their superior aspects (Joseph, 2022).

The most basic autoregressive model, which shows that the difference be-tween both sides of the Dickey-Fuller equations, the model to which the cut off effect and deterministic trend effect are added, and the expanded model obtained through the in-clusion of lagged values of the dependent variable in the model are presented in equa-tions 1, 2, and 3 below.

$$\Delta Y_t = \rho Y_{t-1} + \varepsilon_t \quad (1)$$

$$\Delta Y_t = \mu + \rho Y_{t-1} + \varepsilon_t \quad (2)$$

$$\Delta Y_t = \mu + \beta t + \rho Y_{t-1} + \sum_{j=1}^{p} \rho_i \Delta Y_{t-j} + \varepsilon_t \quad (3)$$

In the equation, ΔY_t shows the time series whose stationarity is tested $\mu + \beta t$, refers to the coefficients that determine whether there is a systematic trend in the time series, and ε_t expresses the random error term. In other words, ε_t is a series with a zero mean and σ^2variance of random variables with independent and normal distribution. The hypotheses to be established in the investigation of the stationarity of Y_t are as follows:

$$H_0: |\rho| \geq 1$$

$$H_1: |\rho| < 1$$

$|\rho| < 1$ If is , Y_t time series approximates a stationary time series when t is $\rightarrow \infty$. If it is $|\rho| = 1$, the time series is not stationary. Another method for understanding if a time series is stationary or not is the Phillips-Perron test. Along with the development of times series theory, new models and tests have been/are being developed to repair the faulty aspects of each model. In the Dickey-Fuller test, it is assumed that the distribution of random errors (shocks) is statistically independent and has a constant variance. In other words, it is assumed that there is no autocorrelation between shocks. Phillips-Perron (PP) developed a new non-parametric test for unit roots. As in the ADF test, the PP test can be developed for three different regression models. However, the simplest model is to be presented here:

$$Y_t = \mu + \rho_1 Y_{t-1} + \varepsilon_t \quad (4)$$

$$(1 - \rho_1 L)Y_t = \mu + \varepsilon_t \quad (5)$$

The main problem in the use of the ADF test is the selection of the lag length. The power and dimension properties of the ADF test are rather sensitive to the number of lags included in the model. Here, the aim is to include error terms in the model that would be sufficient to eliminate autocorrelation. The methods used in determining the appropriate lag number in autoregressive processes are methods such as the Akaike Information Criterion (AIC), the Schwart Information Criterion (SIC), and Hannah Quin (HQ). AIC and SIC criteria are the methods used the most in practice. In order to determine the appropriate lag number, the AIC and SIC information criteria should have the smallest values. In this study, these criteria were considered. The *VAR* model was developed by (Sims, 1980), and the model is based on the Granger causality test. If there are two internal variables in the model, each variable is associated with the lag values until a certain period of both itself and the other internal variables. As stated by Thomas 1997, the general form of VAR (p) model with k variable and p lag is as follows:

$$\begin{aligned} X_{1t} &= a_1 + b_{11}X_{it-1} + b_{12}X_{2t-1} + \cdots + b_{1k}X_{kt-p} + \varepsilon_{1t} \\ X_{2t} &= a_2 + b_{21}X_{1t-1} + b_{22}X_{2t-1} + \cdots + b_{2k}X_{kt-p} + \varepsilon_{2t} \\ X_{kt} &= a_k + b_{k1}X_{1t-1} + b_{k2}X_{2t-1} + \cdots + b_{kk}X_{kt-p} + \varepsilon_{kt} \end{aligned} \quad (6)$$

In equation 6, $\boldsymbol{\varepsilon_{1t}}$ and $\boldsymbol{\varepsilon_{2t}}$ are error terms. The lagged values of X_{1t} affect X_{2t} ', while the lagged values of X_{2t} affect X_{1t} . In this model, there are only lagged values on the right side of the equations, and parameter estimations can be made with the least squares method.

The VAR model is particularly suitable for this study because it allows us to capture the dynamic and mutual interactions between GDP and agricultural/non-agricultural emissions without imposing strict theoretical restrictions on the system. Unlike single-equation models, VAR treats all variables as endogenous, which is essential when investigating potential feedback effects between economic growth and environmental pressures. Additionally, the ADF and PP unit root tests are appropriate tools for ensuring the stationarity of the series, a prerequisite for valid econometric inference in time series analysis. These tests complement each other by addressing different statistical properties of error terms, thus increasing the robustness of the results. The use of lag selection criteria such as AIC and SIC further enhances model suitability, as they ensure the optimal lag length is chosen to avoid problems of autocorrelation and omitted dynamics. Taken together, these features make the VAR framework an appropriate and reliable approach for analyzing the historical co-movements and causal relationships between GDP and emission indicators in this study.

Results

The agricultural emission (agemis), gross domestic products (gdp), and non-agricultural emissions (nonagemis) are accepted as endogenous variables in the VAR analysis. EViews software was employed for the analysis. Previously, stationary analysis was made to understand if the series are stationary. First, ADF and PP tests were applied to the series at the level and then to the first differences, as described above. The results of the tests for stationary and trended models are provided in Table 1.

The series having a unit root shows that it is not stationary. Whether the varia-bles of lwhprice, lwhprdamnt, lbaprice, ldapprice and ldieselprice had a unit root at the logarithmic level, that is whether they had a stationary structure and whether they showed a distribution around a certain mean value were tested through the ADF and PP tests. As a result of the tests applied, it was seen that none of the variables was stationary at their logarithmic levels and that they were stationary at the first differ-ence of logarithmic values (Δ) . The significance levels of the coefficients were lower than critical values (1%, 5%, and 10%).

Table 1. ADF and PP Unit Root Results

Variable	Augmented	Dickey-Fuller Test	Phillips -	Perron Test
	Constant Model	Constant and Trend Model	Constant Model	Constant and Trend Model
agemis	-1.477	-1.331	-1.421	-0.962
nonagemis	0.723	-2.136	2.817	-1.942
gdp	-0.505	-1.525	-0.628	-1.836
Δ agemis	-8.936	-10.151	-8.701	-10.376
Δ nonagemis	-5.971	-6.354	-6.609	-11.319
Δ gdp	-5.924	-5.848	-6.013	-5.945
Test Critical Value %1	-3.596	-4.192	-3.596	-4.192
Test Critical Value %5	-2.933	-3.520	-2.933	-3.520
Test Critical Value %10	-2.604	-3.191	-2.604	-3.191

In determining the lag length, both the Akaike Information Criterion (AIC) and the Schwarz Criterion (SC) were considered. Incorrect determination of the appropriate lag length can lead to inconsistent results in impact-response analyses and variance decomposition stages using these two analyses. If the lag length is larger than necessary, it can increase the mean squared errors of the predictions. Additionally, there is a possibility of higher variance in parameter estimates. If the lag length is calculated to be smaller than necessary, it may result in autocorrelated error terms. Based on the criteria mentioned, a lag length of 4 has been accepted for this study. At lower lag lengths, problems such as heteroskedasticity and serial correlation were encountered in the residuals of the model.

The VAR(4) model created for the variables in the model was examined for stationarity by checking whether the roots of the AR characteristic polynomial lie within the unit circle. Since the roots are inside the unit circle (as shown in Figure 1), it can be said that the generated VAR model exhibits a stationary structure. All moduli calculated by the Eviews software are smaller than the absolute value of one. However, in this study, the unit circle plot of the characteristic roots has been provided.
Regarding the investigation of whether the VAR (2) model created for the variables included in the model was stationary, as the distribution of the reverse roots of the AR characteristic polynomial was inside the unit circle, it can be stated that the VAR model established had a stationary structure (Figure 1). All modulus calculated by EViews software were smaller than the unit value in terms of absolute value. However, in this study, the unit circle view of the characteristic roots is presented.

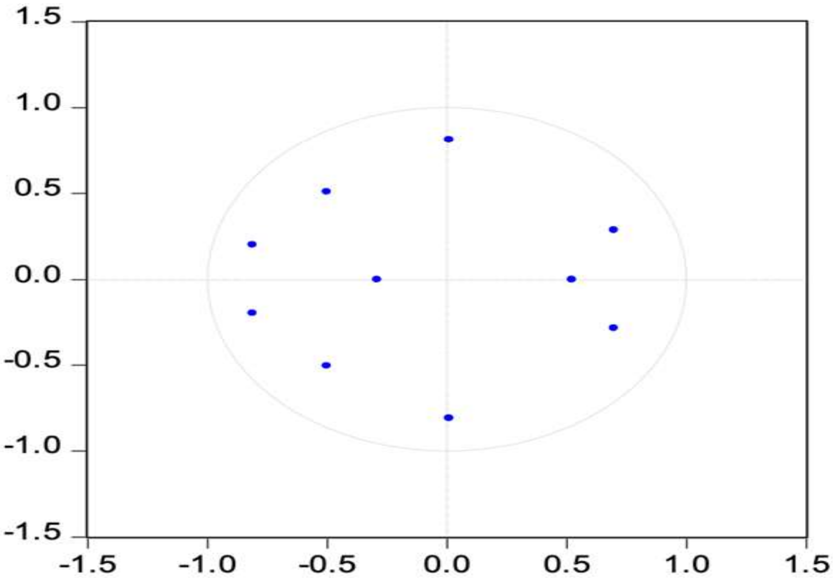


Figure 1. The stability graphic of VAR(4) Model

The estimation results for the VAR(4) model created according to the deter-mined lag length are presented in Table 2. The coefficients for Equation 3 are shown in Ta-ble 3. In the model explaining agricultural emissions (agemis), the coefficient of one-period lagged agricultural emissions (agemis(t-1)) exhibits a statistically significant negative effect at a significance level of 0.1.

In the same model, the coefficient of the one-period lagged non-agricultural emissions variable (nonagemis(t-1)) exhibits a statisti-cally significant positive effect at a significance level of 0.1, and the coefficient of the two-period lagged GDP variable (gdp(t-2)) shows a statistically significant positive effect at a significance level of 0.05. In the model explaining non-agricultural emissions (no-nagemis), the one-period lagged agricultural emissions variable (agemis(t-1)) shows a sta-tistically significant negative effect at a significance level of 0.1, the four-period lagged ag-ricultural emissions variable (agemis(t-4)) exhibits a statistically significant negative effect at a significance level of 0.1, the one-period lagged non-agricultural emissions variable (nonagemis(t-1)) shows a statistically significant positive effect at a significance level of 0.1, and the two-period lagged GDP variable (gdp(t-2)) demonstrates a statistically significant positive effect at a significance level of 0.1.

In the model explaining the GDP variable, only the coefficient of its own variable at the second lag (gdp(t-2)) is statistically significant and positively significant at a significance level of 0.1. In this study, the first model, which al-lows us to understand whether the hypothesized relationships occur or not, yielded an R-squared value of 0.517.

The model explaining non-agricultural emissions achieved an R-squared value of 0.988, and the model with GDP as the dependent variable resulted in an R-squared value of 0.403. From this perspective, we understand that the relationship between non-agricultural emissions and GDP is higher compared to other relationships examined in the study.

Table 2. VAR (4) Model Results

	agemis	nonagemis	gdp
$agemis_{(t-1)}$	-10.354*	-10.982*	-31.269
$agemis_{(t-2)}$	0.002	-0.231	2.284
$agemis_{(t-3)}$	5.599	6.290	-6.068
$agemis_{(t-4)}$	-0.513	-0.558*	-1.951
$nonagemis_{(t-1)}$	9.107*	10.656*	28.012
$nonagemis_{(t-2)}$	-9.727	-10.118	-32.095
$nonagemis_{(t-3)}$	-5.027	-5.864	8.182
$nonagemis_{(t-4)}$	5.682	6.356	-3.979
$gdp_{(t-1)}$	0.072	0.070	0.030
$gdp_{(t-2)}$	0.156**	0.166**	0.511*
$gdp_{(t-3)}$	0.104	0.116	0.348
$gdp_{(t-4)}$	0.067	0.077	0.091
constant	-0.260	-0.212	-0.925
R	*0.517*	*0.988*	*0.403*
F	*1.252*		
AIC	*-5.162*		
SC	*-4.538*		

*Significancy level at p<0.01

**Significancy level at p<0.05

***Significancy level at p<0.01

In the research, Granger causality analysis was conducted to understand the cause-effect relationship between variables. If all variables used in the model are of the same order, Granger causality test can be applied by Gujarati(Gujarati, 2004).

Since all variables in the VAR(4) model explaining the relationship between GDP and agriculture are of the first order, Granger causality test could be applied. As can be seen from Table 3, the non-agricultural emissions variable is not the cause of GDP and non-agricultural emissions *(p=0.108 > 0.05 and p=0.338 > 0.05).* In other words, since the non-agricultural emissions variable is not the Granger cause of the GDP variable, changes in non-agricultural emissions will not precede changes in GDP.

Therefore, when the regression of the non-agricultural emissions variable with other variables includes its past or lagged values, the prediction does not significantly improve. Similarly, non-agricultural emissions and agricultural emissions are not seen as the Granger cause of GDP: ($p=0.469 > 0.10$ and $p=0.580 > 0.05$). Non-agricultural emissions also do not exhibit Granger causality with GDP and agricultural employment: ($p=0.134 > 0.10$ and $p=0.116 > 0.05$).

Although the results of the current study are not consistent with Jiang and Yu (2023) regarding the Granger causality between GDP and non-agricultural GHG emissions, it is important to consider that Türkiye, as an emerging country, focuses on and monitors heavy-industrial emissions. This result is considered a concern for countries experiencing two-way causality, as indicated by several research papers (Chaabouni and Saidi, 2015).

Table 3. VAR / Granger Causality Results

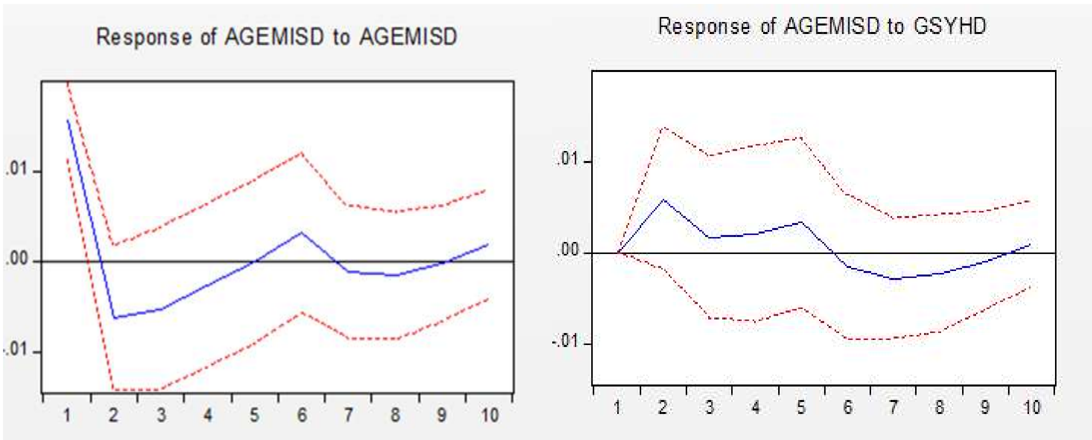
Dependent Variable: agemis	**x^2 value**	**df**	***p-value***
gdp	7.586	4	0.108
nonagemis	4.533	4	0.338
Dependent Variable: gdp	**x^2 value**	**df**	***p-value***
agemis	3.556	4	0.469
nonagemis	2.866	4	0.580
Dependent Variable: nonagemis	**x^2 value**	**df**	***p-value***
agemis	7.033	4	0.134
gdp	7.385	4	0.116

VAR analysis provides explanatory information regarding the relationships between variables. Variance decomposition analysis is indeed a part of VAR analysis, and it shows the proportion of movements caused by a variable's own shocks compared to the changes resulting from shocks of other variables. As shown in Table 4, agricultural emissions are determined by their own shocks in the short term. In the first period, 100% of the variation in agricultural emissions' standard deviation is attributed to its own shocks. By the end of the 10 periods, 69.4% of the agricultural emissions variation is accounted for by itself, with the remaining 21.6% explained by GDP and non-agricultural emissions. The degree to which GDP and non-agricultural emissions are explained by their own shocks in the short term is higher than agricultural emissions. In the first period, 100% of the variation in GDP's standard deviation is attributed to its own shocks. By the end of 10 periods, GDP accounts for 70% of the variation in its standard deviation. Similarly, by the end of 10 periods, 36.3% of non-agricultural emissions and 69.4% of agricultural emissions are attributed to their own variations.

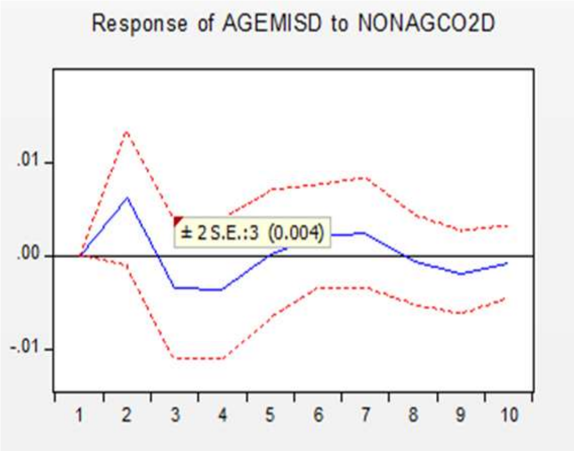
Table 4. Variance Decomposition for the Variables

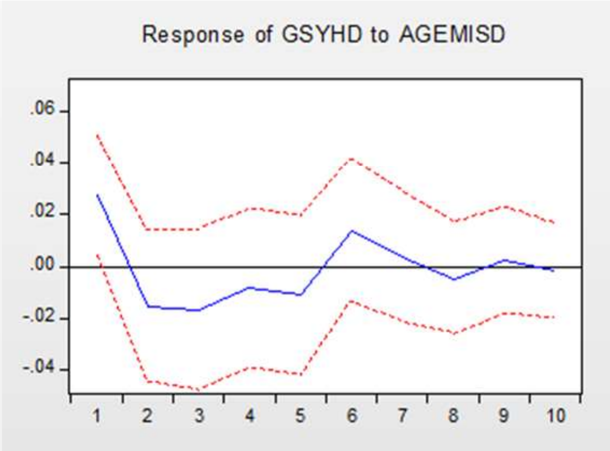
Period	agemis	gdp	nonagemis
1	100.0	100.0	100.0
2	79.3	85.9	82.7
3	77.8	77.4	72.4
4	75.0	74.9	61.5
5	73.1	74.7	47.9
6	72.6	71.8	42.6
7	70.5	70.87	39.5
8	69.9	70.81	37.7
9	69.3	70.2	36.8
10	69.4	70.0	36.3

After obtaining the VAR model, impulse-response functions were examined. Impulse response functions reflect the effect of a one-standard deviation shock in one of the error terms on the current and future values of endogenous variables. In VAR analysis, impulse-response functions play a significant role in determining the dynamic interactions between the variables, identifying symmetric relationships (Akyüz, 2018). The most influential variable on a macroeconomic indicator can be determined through variance decomposition, and whether this variable can be used as a policy tool is also determined by im-pulse-response functions (Gültekin and Hayat, 2016). In Figure 2, graphical representations of the im-pulse-response functions are provided. Here, all possible relationships are depicted. In panel (a) of Figure 2, when a one-unit random shock is applied to the error term of agricultural emission quantity, it illustrates how this shock affects its own variable. In other words, panel (a) of Figure 2 depicts how the emission quantity of agricultural emissions is affected in subsequent periods when a random shock is applied to it. According to the results, a shock in the emission quantity of agricultural emissions positively affects itself, with this effect lasting for approximately 1.5 periods; thereafter, it exhibits a negative effect. It is understood that this effect disappears after 5 periods. Impulse-response analysis and causality analysis should be distinguished from each other. Although im-pulse-response functions provide some clues about causality, the interpretations primar-ily focus on random shocks. In panel (b) of Figure 2, the effect of a one-period shock given to the GDP variable on agricultural emissions is illustrated. A one-standard deviation shock given to GDP positively affects agricultural emissions for 5 periods, and this effect dissipates after the 6th period. From the results, it can be said that in the case of signifi-cant increases in GDP, there is potential for affecting agricultural emissions. As seen in the other panels of Figure 3, shocks in non-agricultural emissions have a positive effect on agricultural emissions for 2 periods; the effect of non-agricultural emissions on GDP is positive for 1 period, then it becomes negative, and these effects dissipate after 5 periods. Similarly, non-agricultural emissions positively affect GDP for 2 periods, then negatively affect it, and the effects disappear in subsequent periods. Shocks in agricultural emis-sions positively affect non-agricultural emissions. At this point, the impact of farmgate emissions on non-agricultural emissions is open to discussion. However, as expected, a one-unit shock given to GDP creates a positive effect on non-agricultural emissions, and this effect dissipates after 8 periods. This finding is consistent with major studies. Jiang and Yu (2023) found that strong shock impacts between GDP and Emission in impulse-response analysis. The high-frequency GDP growth rate data enables a more precise estimation of the impact of economic growth on carbon emissions in different seasons.



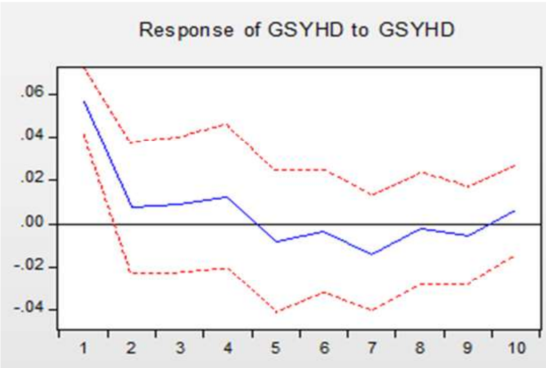
(a) Response of agemis to agemis **(b) Response of agemis to gdp**

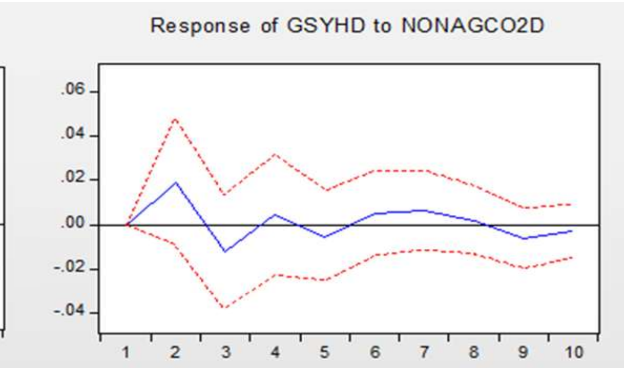




(c) Response of agemis to nonagemis

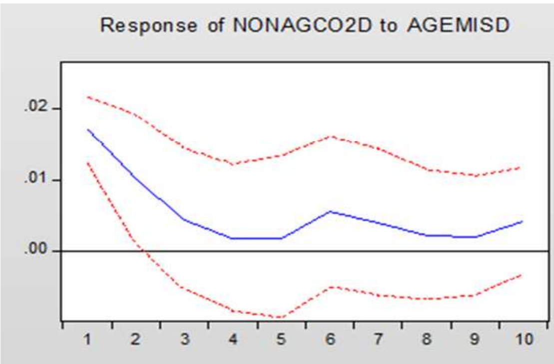
(d) Response of gdp to agemis

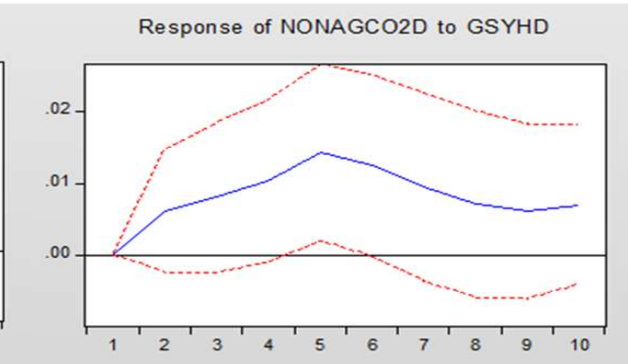




(e) Response of gdp to gdp

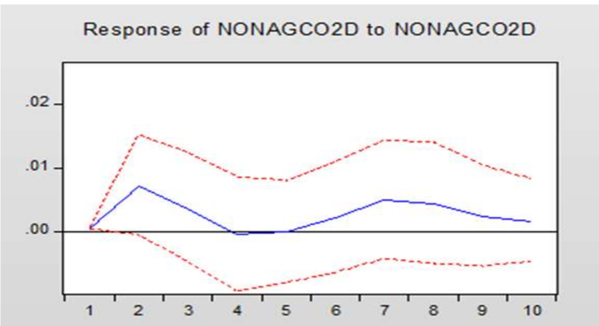
(f) Response of gdp to nonagemis





(g) Response of nonagemis to agemis

(h) Response of nonagemis to gdp



(ı) Response of nonagemis to nonagemis

Figure 2. The effect of one S.D.-impulse to other series on dependent variables

In addition to the individual effects of the variables, their common effect on the dependent variable can provide insight to researchers. Table 5 indicates the impact of the double effect of the series on the wheat prices series depending on Wald Tests.

When examining Table 5a and Table 5b, the test results of the double effect of agricultural emissions of GDP in the first and second lags, and the double effect of GDP on agricultural emissions in the first and second lags, can be observed. Since the probability value P=0.350 >0.05, for the joint effect of agricultural emissions in the first and second lags, the coefficients of the first and second lags together are not the cause of GDP. Additionally, in Table 5b, the test statistics with P=0.073 > 0.05 indicate that the joint effect of the first and second lags of GDP is not the cause of agricultural emissions.

and P=0.093 > 0.05 indicate that the fertilizer and diesel prices do not have a dual effect on wheat prices.

Table 5. Impact of the Double Effect of the Series- Wald Tests

Test Statistic	**Value**	**df**	**Probability**
Chi-square	2.09	2	0.350
Null Hypothesis C(14)=C(15)=0			
Normalized Restriction (=0)	**Value**		**Std. Err.**
C(14)	-31.26		22.54
C(15)	2.28		20.36

(a) agemis and gdp

Test Statistic	**Value**	**df**	**Probability**
Chi-square	5.208	2	0.073
Null Hypothesis C(6)=C(7)=0			
Normalized Restriction (=0)	**Value**		**Std. Err.**
C(6)	0.156		0.074
C(7)	0.104		0.076

(b) gdp and agemis

When the answers to the hypotheses investigated in the study are examined, it is found that the first hypothesis is rejected because there is no relationship between farmgate emissions and GDP in Türkiye. Efforts to reduce non-farmgate emissions indi-cate that Türkiye needs to give more weight to mitigation-related policies. A study conducted in the UK highlights the importance of the EU Green Deal, as it was estimated that per capita GHG emissions from food fell by 32% between 1986 and 2017. It was emphasized that 21% of this 32% reduction is related to improvements in agricultural practices (Stewart et al., 2023a).

Farmgate GHG contributions are closely related to the structures and charac-teristic features of businesses. Until today, it has been commonly said that the Turkish agricultural sector has been inefficient and sluggish. The high number of parcels per farm, the low amount of land per farm, the law of diminishing returns, the scale econo-my in the rural population, and the consequent decrease in the proportional importance of agriculture in GDP are indicators that agriculture is not sustainable. However, with the adoption of green economy and nature-friendly production systems, these statistics can be turned into advantages. In other words, as a result of the aforementioned struc-tural weaknesses, low agricultural chemical usage and low livestock quantity per farm have led to an agriculture sector that contributes less to the increase in greenhouse gases causing climate change. Although there may not be a probability of a reaction like that of farmers in European Union member countries against various restrictions imposed by the Union, there are many policies that policymakers managing agriculture in Türkiye need to implement. As the EU's most important trading partner, regulations similar to the EU's need to be implemented gradually.

Our results, which are consistent with the work of Sarpong (2023), predicting the taxa-tion of non-agricultural emissions, predict that farm emissions are not currently effective. However it is inconsistent with the work of Coderoni and Esposti (2018a), that investigates how the farm-level production choices, and the respective emissions, vary over time also in response to CAP expenditure. Results suggest that CAP expenditure had a role in the evolution of the farm-level emissions.

Many studies have been conducted on the potential responses of agriculture in technical terms for mitigation (Johnson et al., 2017). In addition to research on how countries can im-prove organic farming techniques or address agricultural diseases, research support and investments should also be provided for agricultural mitigation (Jarecki and Lal, 2003). However, the suc-cess of programs to be implemented for mitigation is much more challenging in rural communities deeply rooted in their traditions. Studies indicate that the use of different agricultural techniques could reduce emissions from agriculture by up to 30%. Some ag-ricultural techniques and management shifts such as reducing tillage, eliminating fal-low and keeping the soil covered with residue, cover crops or perennial vegetation, avoiding over application and using split N application rates to meet plant need, ma-nipulating animal diet and manure management practices to reduce CH_4 and N_2O emission. Lal (2007) pointed out that simply reducing tillage could lead to a 15% decrease in emissions from agriculture. Finding producers in underdeveloped regions who are willing to abandon the cultivation and tillage techniques they have been using for centu-ries and transition to environmentally friendly production techniques, while also ad-dressing productivity issues, may be challenging. Environmental-friendly agricultural techniques to be implemented should consider trade-offs based on geographical and climatic conditions, and they should be introduced to country farmers and accompanied by rational policies accordingly.

A situation analysis prioritizing the determination of the extent to which farms at each scale emit carbon in Türkiye should be conducted initially. The expecta-tion is that carbon emissions decrease as the scale of the operation increases. However, it should not be overlooked that small-scale operations may contribute to increasing GHG emissions due to reasons such as inefficient waste disposal, inability to utilize biogas, and inefficient production methodologies (Prosperi et al., 2020). Some farms in Spain and Italy, despite being smaller in scale, have been found to be more successful in developing practical solutions closely aligned with the directives of the EU's Green Deal (Ravani et al., 2024). After presenting the current situation, it is necessary for the agriculture and food system in Türkiye to de-velop a series of supply and demand-oriented strategies under mitigation policies, and to determine policies in the short term for agricultural production and in the medium to long term for food consumption and processing habits. The supply-side measures aim to reduce the emission intensity of agricultural production through environment-friendly practices as mentioned above. The demand-side measures aim to reduce emissions through waste reduction and dietary change (Garvet et al. 2022).

The second hypothesis of the study has also been rejected as no relationship was found between non-agricultural emissions and GDP in Türkiye. There are also studies in the literature stating that adaptation to climate change should be started from metropol-itan cities (Boyd et al., 2022). At this point, urban settlements should be started for the adaptation and mitigation of non-agricultural emissions. Indeed, we may easily state that Istanbul, which is metropolitan city, and Izmit, industrial area, may become initial regions in Tü-rkiye's response to mitigation policies. If the current study had been conducted as a re-gional study, it could have revealed different results for the Marmara Region.

Our findings diverge from several EU-based studies, particularly regarding the absence of a significant causal link between GDP and farm-level emissions in Türkiye. In contrast, research within the EU (e.g., Coderoni and Esposti, 2018b) shows that Common Agricultural Policy (CAP) expenditures have influenced farmers' production choices and, consequently, emission trajectories. This difference can be attributed to structural and institutional contexts: while EU agriculture is more consolidated and responsive to CAP incentives, Türkiye's fragmented landholding structure and lower use of chemical inputs result in weaker linkages between growth and agricultural emissions. Similarly, while UK studies highlight that 21% of emission reductions were achieved through farm-level improvements under the EU Green Deal (Stewart et al., 2023b), such supply-side improvements are less evident in Türkiye, where demand-side measures such as dietary change and food processing policies may play a more immediate role. On the other hand, Türkiye's relatively low farm input intensity and smaller livestock numbers create a baseline of lower emissions compared to some EU counterparts, partially explaining why Turkish farmers have not responded with the same level of protest as seen in EU countries. By situating Türkiye's results within the broader European literature, it becomes clear that mitigation in Türkiye may follow a different sequencing: starting from demand-driven changes and urban policies, before advancing toward structural transformations at the farm level.

Conclusions

In this study investigating the relationship between agricultural and non-agricultural greenhouse gas emissions and economic growth, i.e., GDP, the situation of Türkiye during the EU accession process has been examined. Despite all the de-bates, the EU has begun transitioning to a mitigation policy with the EU Green Deal to prevent climate change, experiencing stages of increasing agricultural production, en-hancing competitiveness in international agricultural trade, and sustainability along the way. While the sole common denominator among farmer protests observed in various countries across Europe may not be the transition to sustainable agricultural strategies, EU leaders are nonetheless curious about the response agriculture will provide in pre-venting climate change. Strategies that are likely to also influence the trade regime should be taken into consideration by Türkiye. As a country that historically hasn't been able to benefit from EU funds and whose economy hasn't grown as much as the EU-15, Türkiye is showing a high economic growth rate and rapidly advancing through the stage of competitiveness in international agricultural trade. Although neither agricultur-al nor non-agricultural emissions were identified as drivers of GDP in the analysis re-sults, as a country that has not taken concrete steps regarding agriculture and global warming, Türkiye may face environmental-political pressures in the near future. Strate-gies should be devised for agricultural production, agricultural processing, and con-sumption stages. Understanding the impact of supply and demand-side changes on ag-ricultural emissions in the medium and long term provides crucial insights for devising emissions reduction policies. Those political strategies are essential for identifying policy levers for further emissions mitigation.

The transition of rural residents in Türkiye to alter agricultural techniques that have been practiced for centuries for mitigation purposes may require time. The current findings of the paper do not dictate this. However, in a growing economy, transitioning to regional studies and demand-side mitigation policies for non-agricultural emissions can be implemented more readily. The process that began with supply-side mitigation efforts in countries like the EU, where farmers were structurally more prepared, could start with demand-side mitigation efforts in Türkiye (such as dietary changes, measures in the processing industry, etc.). The wave of change observed in consumers and agricultural raw material processors could lead towards farmgate miti-gation efforts.

Since the human and ecosystem-centered structure of agricultural policies causes it to have a complex, multifaceted, and sometimes unpredictable character, it is possible to predict that the adaptation speed of the sector will vary significantly across regions and subheadings. Agricultural policies, which are at the core of the changing policies of the EU, are also among the sectors in need of transformation the most due to their central position in the human-nature relationship. However, the complex and multi-layered structure of the sector causes a slow pace of change. In this respect, continuous monitoring, and implementation of incentive policies in Türkiye should be accelerated in the process of transition to smart, digital and environmentally friendly production and consumption models that will facilitate mitigation strategies against climate change. Although the initial costs of the basic elements that will accelerate and, more importantly, make permanent the transformations in agricultural policies are high, their long-term benefits will be high.

In the setup of VAR models, it is not important which variable is exogenous or which variable is endogenous. It can be argued that VAR models are more advanta-geous than classical simultaneous equations regression models. Each equation can be forecasted separately, and the lag order of each model can also differ. However, VAR models, which offer many analyses, cannot be used in research where forecasting is im-portant. At this point, after analyzing the presence of relationships between variables and conducting analyses such as variance decomposition, forecasting can be performed with other econometric models. Researchers willing to contribute to this study can work with regional data. This way, it may be possible to propose different strategies for ad-vanced industrial regions and advanced agricultural basins.

Based on the study findings and in light of the EU's experience, Türkiye should pursue a phased and structured approach to climate mitigation in agriculture and non-agricultural sectors:

Short-term (1–3 years): Prioritize demand-side mitigation measures such as dietary change campaigns, food waste reduction, and efficiency improvements in the processing industry.

Launch pilot programs in metropolitan and industrial regions (e.g., Istanbul, Izmit) to test adaptation and mitigation strategies for non-agricultural emissions.

Improve monitoring and data collection systems on farm-level emissions to establish a reliable baseline for policymaking.

Medium-term (3–7 years): Gradually introduce supply-side policies, including incentives for reduced tillage, crop rotation, manure management, and organic farming practices.

Provide targeted subsidies and credit schemes for farmers investing in low-emission technologies and smart farming methods.

Strengthen institutional capacity for implementing EU-compatible regulations, especially in trade-sensitive agricultural subsectors.

Long-term (7+ years): Align Türkiye's agricultural and environmental policies with the EU Green Deal by adopting integrated strategies across production, processing, and consumption stages.

Support the structural transformation of farms (e.g., consolidation, modernization) to overcome fragmentation and improve efficiency while lowering emissions.

Foster a culture of innovation and knowledge transfer, ensuring that environmentally friendly practices become permanent features of the rural economy.

This phased roadmap acknowledges the structural constraints of Turkish agriculture while ensuring that mitigation strategies are both feasible and politically sustainable. It emphasizes a balanced progression from demand-side to supply-side interventions, mirroring EU experiences but adapted to Türkiye's socio-economic and institutional realities.

Authors' Contribution

Authors declare the contribution of the authors is equal.

Conflicts of Interest Statement

The authors have declared no conflict of interest.

References

Akyüz, H.E., 2018. Statistical Analysis of Climatic Variables with Vector Autoregression Model (VAR). Int. J. Eng. Res. Dev. 10: 183–192.

Appiah, K., Du, J., Poku, J., 2018. Causal relationship between agricultural production and carbon dioxide emissions in selected emerging economies. Environmental Science and Pollution. 25: 24764-24777.

Baldock, D., Bartley, J., Framer, M., Hart, K., Lucchesi, V., Silcock, P., Zobbe, H., Pointereau, P., 2007. Evaluation of the environ-mental impacts of CAP (common agricultural policy) measures related to the beef and veal sector and the milk sector. Working Report of the Institute for European Environmental Policy for DG Agriculture, London.

Boyd, D., Pathak, M., Diemen, R., Skea, J., 2022. Mitigation co-benefits of climate change adaptation: A case-study analysis of eight cities. Sustainable Cities and Society. 77: 1-11.

Carbonbrief, 2024. Carbon Brief Clear on Climate Web Page. https://www.carbonbrief.org/analysis-how-do-the-eu-farmer-protests-relate-to-climate-change/ , (Accessed on 21 February 2024).

Chaabouni S., Saidi K., 2017. The dynamic links between carbon dioxide (CO_2) emissions, health spending and GDP growth: a case study for 51 countries. Environmental Research. 158: 137–144.

Coderoni, S., Esposti, R., 2018a. CAP payments and agricultural GHG emissions in Italy. A farm-level assessment. Science of the Total Environment. 627: 427-437.

Coderoni, S., Esposti, R., 2018b. CAP payments and agricultural GHG emissions in Italy: An analysis of farm-level data. Environmental Science & Policy. 83: 239–248.

EDF, 2021. EU Green Deal- Main Elements and Roadmap. Economic Development Foundation of Türkiye.

FAO, 2019. FAO Corporate Statistical Database. http://www.fao.org/faostat/en/#data/GT ,(Accessed on March 2024).

Garvey, A., Norman, J., Barrett, J. 2022. Reducing The UK's Food Footprint: Demand-Side Action for More Palatable Food emissi-ons.'CREDS Policy Brief 020. Centre for Research into Energy Demand Solutions. Oxford, UK.

Garvey, A., Norman, J., Owen, A., Barrett, J., 2021. Towards net zero nutrition: the contribution of demand-side change to mitigating UK food emissions. Journal of Cleaner Production. 290:125672

Gujarati, D.N., 2004. Basic Econometrics, New York: McGraw-Hill.

Gurluk, S., 2009. Economic growth, industrial pollution and human development in the Mediterranean Region. Ecological Economics. 68(8-9): 2327-2335.

Gurluk, S., 2015. Assessing Agri-Environmental Management and Inorganic Fertilizer Consumption Using Environmental Indicators. Outlook on Agriculture. 44(2): 135-141

Gültekin, Ö.E., Hayat, E.A., 2016. Analysis of Factors Affecting The Gold Prices Through Var Model:2005-2015 Period. Ege Academik Review. 16(4): 611-625.

Haider, A., Arooj B,, Muhammad I.H., 2020. Impact of agricultural land use and economic growth on nitrous oxide emissions: Evidence from developed and developing countries. Science of Total Environment. 741: 140421. https://doi.org/10.1016/j.scitotenv.2020.140421

Han, J., Du, T,, Zhang, C., Qian, X., 2018. Correlation analysis of CO_2 emissions, material stocks and economic growth nexus: Evi-dence from Chinese provinces. Journal of Cleaner Production. 180: 395-406.

Harris, J. M., 2002. Environmental and Natural resources economics: A contemporary approach. Houghton Mifflin College Div; First Edition, USA.

IPCC, 2006. Intergovernmental panel on climate change guidelines for national greenhouse gas inventories volume 4: agriculture, forestry and other land use. ISBN: 4-88788-032-4, Japan.

Jarecki, M., Lal, R., 2003. Crop management for soil carbon sequestration. Critical Reviews in Plant Sciences. 22: 471-502.

Jiang, W., Yu, Q., 2023. Carbon emissions and economic growth in China: Based on mixed frequency VAR analysis. Renewable and Sustainable Energy Reviews. 183(3): 113500.

Johnson, J.M., Franzluebbers, A.J., Weyers, S.L., Reicosky, D,C., 2017.Agricultural opportunities to mitigate greenhouse gas emissions. Environmental Pollution. 150: 107-124.

Joseph, M., 2022. Modern Time Series Forecasting with Python: Explore Industry-Ready Time Series Forecasting Using Modern Machine Learning and Deep Learning; Packt Publishing: Birmingham, UK.

Klemedtsson, A. K., Klemedtsson, L., Berglund, K., Martikainen, P., Silvola, J., Oenema, O., 1997. Greenhouse gas emissions from farmed organic soils: A review. Soil Use and Management. 13: 245–250.

Kyriazil, A., Miro, J., 2023. Towards a socially fair green transition in the EU?An analysis of the Just Transition Fund using the Multiple Streams Framework. Comparative European Politics. 21: 112–132.

Lal, R., 2007. Carbon management in agricultural soils. Mitigation and Adaptation Strategies for Global Change. 12: 303-322.

Muhadinovic, M., Djurovic, G., Bojaj, M.M., 2021. Forecasting Greenhouse Gas Emissions and Sustainable Growth in Montenegro: a SVAR Approach. Polish Journal of Environmental Studies. 30: 4115-4129.

Nguyen, C.P., Le, T.H., Schinckus, C., Su, T.D., 2020. Determinants of agricultural emissions: panel data evidence from a global sample. Environment and Development Economics. 2: 109-130.

Niles, M.T., Ahuja, R., Barker, T., Esquivel, J., Gutterman, S., Heller, M.C., Mango, N., Portner, D., Raimond, R., Tirado, C., Vermeulen, S., 2017. Climate change mitigation beyond agriculture: a review of food system opportunities and implications. Renewable Agriculture and Food Systems. 33: 297 – 308.

Özçicek, Ö., McMillin, D., 1999. Lag Length Selection in Vector Autoregressive Models: Symmetric and Asymmetric Lags. Appl. Econ., 31: 517–524.

Poore, J., Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. Science. 360: 987–92.

Prosperi, P., Bloise, M., Tubiello, F.N., Conchedda, G., Rossi, S., Boschetti, L., Salvatore, M., Bernoux, M., 2020. New estimates of greenhouse gas emissions from biomass burning and peat fires using MODIS Collection 6 burned areas. Climate Change. 161: 415–32.

Ravani, M., Georgiou, K., Tselempi, S., Monokrousos, N., Ntinas, G.K., 2024. Carbon Footprint of Greenhouse Production in EU—How Close Are We to Green Deal Goals? Sustainability. 16(1): 191. https://doi.org/10.3390/su16010191.

Rosenzweig, C., Mbow, C., Barioni, L.G., 2020. Climate change responses benefit from a global food system approach. Nature Food. 1: 94–7.

Saidi, K., Hammami S., 2015. The impact of energy consumption and CO_2 emissions on economic growth: fresh evidence from dynamic simultaneous-equations models. Sustain Cities Soc., 14: 178–186.

Sarpong, K.A., Xu, W., Gyamfi, B.A., Ofori, E.K., 2023. Can environmental taxes and green-energy offer carbon-free E7 economies? An empirical analysis in the framework of COP-26. Environmental Science and Pollution Research. 30: 51726–51739.

Sciencenews, 2019. Fertilizer produces far more greenhouse gases than expected. https://www.sciencenews.org/article/fertilizer-produces-far-more-greenhouse-gas-expected, (Accesed: 23 February 2024).

Sevuktekin, M., Cinar, M., 2017. Econometric Time Series Analysis; Dora Publishing: Bursa.

Sims, C., 1980. Macroeconomics and reality. Econometrica. 48: 1–48.

Smol, M., 2022. Is the green deal a global strategy? Revision of the green deal definitions, strategies and importance in post-COVID recovery plans in various regions of the world. Energy Policy. 169: 113-152.

Stewart, G. B., Smith, L. G., Jones, P. J. 2023. Food-related greenhouse gas emissions in the UK: Evidence from the Green Deal and beyond. Journal of Cleaner Production. 387: 135890.

Stewart, K., Balmford, A., Scheelbeek, P., Doherty, A., Garnett, E.E., 2023a. Changes in greenhouse gas emissions from food supply in the United Kingdom. Journal of Cleaner Production. 410(2): 137273.

Szpilko, D., Ejdys, J., 2022. European Green Deal–research directions. a systematic literature review. Ekonomia i Środowisko. 2: 8-38.

Thomas, R.L., 1997. Modern Econometrics—An Introduction; Addison Wesley Longman: London, UK.
UN, 2024. United Nations. Climate Action ,(Accessed 14 03 2024).
Uzel, G., Gürlük, S., Aşlak, E., Karaer, F., 2022. Land use preferences considering resource economics: case of organic versus con-ventional wheat production in Turkey. Environment, Development and Sustainability. 24: 14375-14392.