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## Article

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# Policy support and agricultural greenhouse gas emissions in BRICS-T countries: The role of financial development, markets, and institutions

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## ABSTRACT

This study explores the impact of agricultural support policies on greenhouse gas emissions in BRICS-T countries (Brazil, Russia, India, China, South Africa, and Türkiye), emphasizing the role of financial development, market structures, and institutions. Using annual data from 2000 to 2021, the research employs advanced panel time-series econometric techniques, including the Augmented Mean Group (AMG) estimator and the Westerlund and Edgerton cointegration test, to assess long-term relationships. Findings indicate that economic growth significantly contributes to rising agricultural emissions, while the influence of financial development varies across countries. In Türkiye and South Africa, financial institutions play a crucial role in promoting sustainable agricultural investments, thereby helping to mitigate emissions. Policy recommendations include redesigning subsidy mechanisms to support eco-friendly farming, integrating carbon pricing into agricultural strategies, and strengthening financial institutions' role in green investments. By examining the intersection of agriculture, emissions, and finance, this study offers valuable insights for sustainable policy development in emerging economies.

## 1. Introduction

Agriculture, while being a vital sector for global food security, also exerts both direct and indirect impacts on environmental quality. In recent years, the environmental consequences of agricultural production processes have been increasingly discussed, bringing sustainable farming methods to the forefront (Appiah et al., 2018). One of the most critical concerns is the contribution of agricultural activities to carbon emissions, which plays a significant role in the fight against climate change. The agricultural sector is responsible for approximately 18–30 % of global greenhouse gas (GHG) emissions, notably releasing methane and nitrous oxide (Iyke-Ofoedu et al., 2024). The use of fossil fuels, fertilizers, and pesticides in farming not only intensifies atmospheric carbon accumulation but also leads to soil and water pollution (Pata, 2021). Therefore, adopting eco-friendly agricultural practices and incorporating innovative technologies hold the potential to minimize

these environmental impacts. The environmental impact of agriculture, however, extends beyond carbon emissions. The overuse and contamination of water resources remain pressing issues. Intensive agricultural irrigation and heavy reliance on chemical fertilizers contribute to the depletion and pollution of water bodies (Balogh, 2022). Excessive extraction of groundwater can lead to long-term water scarcity, adversely affecting agricultural productivity. Implementing sustainable water management practices is crucial in addressing these challenges (Tongwane et al., 2020). Technologies such as drip irrigation and agroecological approaches can play a pivotal role in conserving water resources. Additionally, promoting eco-friendly practices like the use of organic fertilizers and biological pest control is essential to reduce water contamination caused by agricultural activities (Raihan & Tuspekova, 2022).

Biodiversity loss is another significant environmental consequence of agricultural activities. Industrial farming practices that promote

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monoculture cultivation lead to ecosystem degradation and a reduction in genetic diversity (Balogh & Jámor, 2020). This decline in biodiversity poses risks to both ecosystem health and long-term agricultural productivity. Agroecological farming methods and the conservation of local seed varieties are critical for preserving biodiversity. Moreover, protecting natural habitats and implementing environmentally friendly farming techniques are essential for ensuring sustainability (Lacombe et al., 2018). Environmental taxes and policies serve as vital tools for mitigating the adverse effects of agriculture on environmental quality. By imposing such taxes, harmful agricultural practices can be reduced, while encouraging the adoption of sustainable methods (Doğan, 2019). Integrating technological innovations into farming can also facilitate the development of low-carbon production processes, enhancing overall environmental quality. For instance, precision agriculture technologies, soil analysis systems, and biotechnological solutions can significantly contribute to reducing carbon emissions and strengthening sustainable farming practices (Cillis et al., 2018). In conclusion, adopting sustainable agricultural practices is essential to minimize the negative impacts of agriculture on environmental quality. Developing and implementing more conscious policies within the agricultural sector is vital to balancing global food security with environmental sustainability (Iyke-Ofoedu et al., 2024). Looking ahead, the integration of technological innovations, sustainable water management, biodiversity-supporting practices, and environmental taxation policies can substantially reduce agriculture's environmental footprint. Raising farmer awareness, providing government support, and fostering international cooperation will further enhance the effectiveness of these efforts. To reduce agriculture's ecological footprint and build a sustainable future, collaboration among all stakeholders is imperative (Sun et al., 2024).

The intricate link between financial development and environmental quality has attracted significant attention in recent years, especially as the global community faces the pressing challenges of climate change and environmental degradation. Financial development, which encompasses the expansion of financial institutions, markets, and instruments, plays a dual role in this complex dynamic. On one hand, it can stimulate economic growth and encourage technological innovations that support environmental sustainability. On the other hand, it can contribute to environmental degradation by financing industries that heavily rely on natural resources and carbon-intensive energy sources (Usman et al., 2022). The industrialization process, driven by economic expansion and financial development, has historically been associated with rising GHG emissions and ecological harm. A notable example is the increase in carbon dioxide (CO<sub>2</sub>) emissions, which accounts for roughly 75 % of global GHG emissions, directly linked to intensive industrial activities fueled by financial growth (Shahbaz et al., 2021). Financial institutions and markets, by providing easier access to capital, often enable industries to expand operations without adequately considering their environmental impact (Aytun et al., 2024). This issue is particularly evident in developing economies where environmental regulations may be less stringent. However, financial development also has the potential to alleviate environmental harm. Well-structured financial systems can support green investments and renewable energy projects, promoting a transition toward a low-carbon economy (Kirikkaleli & Adebayo, 2021). Empirical studies show that, in the long run, global financial development positively impacts environmental sustainability by boosting renewable energy consumption and fostering technological innovation (Habiba & Xinbang, 2022). This dual effect underscores the importance of implementing financial policies that prioritize sustainable development goals.

Technological innovation, often accelerated by financial development, plays a crucial role in shaping environmental outcomes. Investments in research and development, supported by robust financial systems, can lead to breakthroughs in energy efficiency and the adoption of cleaner production methods (Fatima et al., 2025). For instance, in Sub-Saharan Africa, green technological innovations have been shown

to improve environmental quality when backed by stringent environmental policies and sufficient financial resources (Fatima et al., 2025). Another important dimension of this discussion is the impact of financial inclusion and remittance flows on environmental quality. Studies suggest that remittances can influence environmental outcomes by altering consumption and investment patterns in recipient countries (Aljadani et al., 2023). While remittances can stimulate economic growth and improve household welfare, they may also lead to increased energy consumption and higher CO<sub>2</sub> emissions if not directed toward sustainable projects. In conclusion, the interaction between financial development and environmental quality is multifaceted and context-dependent. Financial growth can drive environmental degradation through industrial expansion and resource exploitation, but it also holds the potential to promote sustainability via green investments and technological advancements (Oanh, 2024). Therefore, policymakers must design financial frameworks that balance economic growth with environmental preservation, ensuring that financial development serves as a catalyst for achieving global sustainability goals.

The connection between economic growth and environmental quality has been a central topic in academic and policy debates for decades. Economic growth, typically measured by increases in Gross Domestic Product (GDP), is often regarded as a primary goal for nations aiming to improve living standards, reduce poverty, and promote technological advancement. However, this pursuit has frequently come at the expense of environmental sustainability, raising significant concerns about global warming, pollution, and resource depletion (Alakbarov et al., 2024). One of the most pressing challenges of the modern era is finding a balance between economic expansion and the need to protect environmental quality. Rapid industrialization, urbanization, and rising energy consumption (hallmarks of economic growth) have contributed to escalating GHG emissions, deforestation, and pollution (Xiong et al., 2016). Sectors such as agriculture and heavy industry are particularly significant contributors to environmental degradation due to their high resource demands and carbon-intensive processes. Research has demonstrated that agricultural activities, through land-use changes, deforestation, and energy-intensive practices, significantly increase CO<sub>2</sub> emissions, thereby worsening climate change (Adebayo et al., 2024; Xiong et al., 2016). The complexity of the economic growth-environment nexus is further influenced by financial development and support mechanisms. Financial systems play a dual role in this dynamic. On one hand, well-structured financial markets can facilitate investments in sustainable technologies, renewable energy, and environmentally friendly infrastructure (Fakher et al., 2022). On the other hand, in the absence of adequate regulation, they can promote capital-intensive industries that contribute to environmental degradation (Xuezhou, Manu, & Akowuah, 2022). Agriculture, which remains a vital component of economic growth in many developing countries, presents a paradox in terms of environmental sustainability. While it is essential for food security and rural development, agricultural practices often lead to significant environmental challenges, including soil degradation, water pollution, and high levels of GHG emissions (Adebayo et al., 2024). Financial support in the form of subsidies and incentives can influence agricultural practices in both positive and negative ways. Targeted subsidies that promote sustainable farming methods can reduce environmental harm, whereas indiscriminate financial support may lead to overproduction and environmentally harmful practices (Aziz et al., 2024). The relationship between economic growth and environmental quality is inherently multifaceted. Achieving a balance requires comprehensive policies that integrate economic, environmental, and social objectives (Wahab et al., 2024). Financial development, agricultural practices, and trade policies must be aligned to support sustainable growth. Policymakers need to implement regulations and incentives that promote environmentally friendly practices while simultaneously encouraging economic development. Only through such integrated approaches can societies achieve long-term sustainability and build resilience against environmental

challenges.

This study makes a significant contribution to the existing literature by addressing critical gaps in the relationship between agricultural support policies, financial development, economic growth, and environmental sustainability in BRICS-T countries. The key motivations and contributions of this research are as follows: i) BRICS-T countries (Brazil, Russia, India, China, South Africa, and Türkiye) play a crucial role in global agricultural production while also being among the largest emitters of agricultural GHG emissions. Together, they account for a significant share of the global food supply, yet their agricultural support policies and environmental impact remain underexplored in a comparative framework. Understanding how agricultural policies influence emissions in these economies is essential for designing effective climate mitigation strategies. ii) Unlike developed economies where agricultural subsidies are primarily structured around environmental sustainability, BRICS-T countries exhibit heterogeneous and evolving subsidy policies. While Brazil and Türkiye have implemented some sustainability-focused incentives, China, India, and Russia continue to provide high-emission subsidies that encourage resource-intensive agricultural expansion. This study fills a gap in the literature by investigating how different policy structures within BRICS-T shape environmental outcomes. iii) The role of financial institutions and markets in shaping agricultural sustainability remains an underexplored area, particularly in emerging economies. This study distinguishes between financial institutions and financial markets, providing novel insights into how different financial structures influence the effectiveness of agricultural subsidies in reducing or exacerbating GHG emissions. Given that BRICS-T countries are experiencing rapid financial sector transformations, examining their role in mitigating environmental degradation is highly relevant. iv) The study employs advanced panel time-series econometric techniques, including the [Breitung and Das \(2005\)](#) unit root test, the [Westerlund and Edgerton \(2007\)](#) LM bootstrap panel cointegration method, and the Augmented Mean Group (AMG) estimator. These methods ensure robustness against cross-sectional dependence and slope heterogeneity, allowing for reliable long-term policy insights that account for country-specific differences within BRICS-T. v) Unlike previous studies that examine agricultural policies and environmental impact in isolation, this research explores the interactive effects of economic growth and financial development on agricultural emissions. The findings reveal that while economic expansion intensifies emissions, well-structured financial institutions can counterbalance environmental harm by promoting green agricultural investments. This highlights the need for integrated policy frameworks that balance economic growth, food security, and climate commitments in emerging economies. The remainder of this paper is structured as follows: Section 2 reviews the existing literature on the relationship between agricultural policies, financial development, and environmental sustainability. Section 3 describes the dataset and outlines the econometric methodology. Section 4 presents the empirical findings and discusses their implications. Finally, Section 5 concludes the study by summarizing key policy recommendations and outlining directions for future research.

2. Literature review

This section provides a general overview of the existing literature on the impact of agriculture, financial development, and economic growth on environmental quality. Studies in the field have produced diverse results based on different methods, time periods, and country contexts. While some findings align across various research, others present contrasting or even conflicting outcomes. This variability highlights the complexity of the factors influencing environmental quality and underscores the importance of context-specific dynamics. The aim of this review is to outline key trends in the literature and offer a comprehensive framework on the subject.

2.1. Literature evaluation and research gap

The existing literature encompasses a wide range of studies examining the effects of agriculture, financial development, and economic growth on environmental quality from various perspectives. Most research exploring the relationship between agriculture and environmental quality highlights that agricultural activities tend to increase CO<sub>2</sub> emissions. Studies by [Rehman et al. \(2022\)](#), [Xiong et al. \(2016\)](#), [Appiah et al. \(2018\)](#), [Yurtkuran \(2021\)](#), and [Iyke-Ofoedu et al. \(2024\)](#) emphasize the adverse environmental impacts of agricultural practices. Conversely, some studies, such as those by [Bas et al. \(2021\)](#), [Pata \(2021\)](#) and [Balogh \(2022\)](#), suggest that agriculture can positively influence environmental quality under certain conditions (see [Table 1](#)). The relationship between financial development and environmental quality presents more complex findings. While [Kirikkaleli and Adebayo \(2021\)](#) and [Anwar et al. \(2022\)](#) report that financial development increases CO<sub>2</sub> emissions, other studies, including those by [Khan and Ozturk \(2021\)](#) and [Habiba and Xinbang \(2022\)](#), argue that it can enhance environmental quality. Additionally, research by [Xu et al. \(2022\)](#) and [Oanh \(2024\)](#) presents mixed results, indicating that the environmental impact of financial development may vary depending on specific contexts (see [Table 2](#)). Studies examining the relationship between economic growth and environmental quality also yield diverse outcomes. [Zhang et al. \(2017\)](#) and [Alakbarov et al. \(2024\)](#) find that economic growth contributes to higher CO<sub>2</sub> emissions, whereas [Fan et al. \(2022\)](#) and [Bozatli and Akca \(2024\)](#) suggest that economic expansion can lead to improvements in environmental quality. Some studies, such as those by [Aydin et al. \(2023\)](#), [Sogut et al. \(2025\)](#) and [Nordin et al. \(2025\)](#), support

**Table 1**  
The relationship between agriculture and environmental quality.

| Authors                                     | Countries                                 | Periods   | Method                           | Result                                                             |
|---------------------------------------------|-------------------------------------------|-----------|----------------------------------|--------------------------------------------------------------------|
| <a href="#">Rehman et al. (2022)</a>        | Bhutan                                    | 1980–2020 | ARDL                             | increases CO <sub>2</sub>                                          |
| <a href="#">Xiong et al. (2016)</a>         | China (Hotan)                             | 1999–2013 | decoupling relationship analysis | increases CO <sub>2</sub>                                          |
| <a href="#">Appiah et al. (2018)</a>        | Selected Emerging Economies               | 1971–2013 | FMOLS and DOLS                   | increases CO <sub>2</sub>                                          |
| <a href="#">Kara et al. (2021)</a>          | Türkiye                                   | 1988–2019 | ARDL                             | Mixed Results                                                      |
| <a href="#">Pata (2021)</a>                 | BRIC                                      | 1971–2016 | Fourier ADL                      | Positive impact on environmental quality increases CO <sub>2</sub> |
| <a href="#">Yurtkuran (2021)</a>            | Türkiye                                   | 1970–2017 | ARDL                             |                                                                    |
| <a href="#">Bas et al. (2021)</a>           | Türkiye                                   | 1991–2019 | FMOLS and CCR                    | increases environmental quality lowers CO <sub>2</sub>             |
| <a href="#">Balogh (2022)</a>               | 152 non-EU countries                      | 2000–2018 | FMOLS and DOLS                   |                                                                    |
| <a href="#">Raihan and Tuspekova (2022)</a> | Brazil                                    | 1990–2019 | ARDL-DOLS                        | increases CO <sub>2</sub>                                          |
| <a href="#">Raihan (2023)</a>               | Vietnam                                   | 1984–2020 | ARDL-VECM                        | lowers CO <sub>2</sub>                                             |
| <a href="#">Iyke-Ofoedu et al. (2024)</a>   | South Africa                              | 1992–2021 | ARDL                             | increases CO <sub>2</sub>                                          |
| <a href="#">Ma et al. (2024)</a>            | top eight agricultural emitters countries | 1990–2020 | PMG-ARDL, SC-ARDL                | Increases environmental degradation                                |
| <a href="#">Shahbaz et al. (2024)</a>       | Netherlands                               | 1995–2019 | Fourier Augmented ARDL           | Insignificant impact on environmental quality                      |
| <a href="#">Li et al. (2025)</a>            | 214 countries and territories             | 1990–2021 | structural equation modeling     | Mixed Results                                                      |

**Table 2**

The relationship between financial development and environmental quality.

| Authors                       | Countries                                                                                          | Periods   | Method                                 | Result                                  |
|-------------------------------|----------------------------------------------------------------------------------------------------|-----------|----------------------------------------|-----------------------------------------|
| Kirikaleli and Adebayo (2021) | developed and emerging countries                                                                   | 1985–2017 | FMOLS, DOLS and CCR                    | increases CO <sub>2</sub>               |
| Anwar et al. (2022)           | 15 Asian economies                                                                                 | 1990–2014 | FMOLS and DOLS                         | increases CO <sub>2</sub>               |
| Akca (2021)                   | Türkiye                                                                                            | 1965–2018 | Augmented ARDL                         | Insignificant impact on CO <sub>2</sub> |
| Khan and Ozturk (2021)        | 88 developing countries                                                                            | 2000–2014 | Sys-GMM                                | lowers CO <sub>2</sub>                  |
| Habiba and Xinbang (2022)     | developed and emerging countries                                                                   | 2000–2018 | Sys-GMM                                | lowers CO <sub>2</sub>                  |
| Xu et al. (2022)              | G7 countries                                                                                       | 1986–2019 | NARDL                                  | Mixed Results                           |
| Aljadani et al. (2023)        | top ten countries receiving remittances                                                            | 1980–2018 | Panel quantile regression (PQR) method | Environmental degradation increases     |
| Oanh (2024)                   | 16 low financial development countries (LFDCs) and 29 high financial development countries (HFDCs) | 2015–2020 | PVAR                                   | Mixed Results                           |
| Aytun et al. (2024)           | 19 middle-income countries                                                                         | 1980–2016 | CS-ARDL                                | Environmental quality increases         |
| Fatima et al. (2025)          | Sub-Saharan Africa                                                                                 | 1990–2020 | FMOLS, DOLS and CCR                    | Environmental quality increases         |

the Environmental Kuznets Curve hypothesis, which proposes that economic growth initially leads to environmental degradation but eventually results in improvements in environmental quality after reaching a certain income threshold (see Table 3). Despite the extensive body of research, significant gaps remain in the literature: I) Insufficient examination of country- and region-specific heterogeneities, particularly a lack of in-depth studies on the environmental effects of agricultural subsidies in developing economies, II) Limited research on the distinct impacts of financial development subcomponents (financial institutions and markets) on environmental quality, III) Inadequate analysis of the interaction between agricultural policies and economic growth, especially regarding the environmental impacts of agricultural subsidies within the context of economic expansion, IV) A lack of studies distinguishing the environmental effects of different types of agricultural support, such as direct income subsidies, production incentives, and environmentally-friendly agricultural policies, V) A scarcity of research exploring the intricate interactions among financial development, agricultural policies, and environmental quality using comprehensive econometric models. Addressing these gaps would significantly contribute to the literature and provide policymakers with more effective strategies. Understanding context-specific dynamics is crucial for designing policies tailored to local conditions, ultimately supporting the achievement of environmental sustainability goals.

### 3. Data and methodology

This study analyses the impact of agricultural support policies on agricultural GHG emissions in the BRICS-T sample using annual data for the period 2000–2021. In doing so, the role of economic growth and financial development is also investigated. Accordingly, explanations about the data used in the study and their sources are reported in

**Table 3**

The relationship between economic growth and environmental quality.

| Authors                       | Countries                 | Periods   | Method   | Result                                                                                            |
|-------------------------------|---------------------------|-----------|----------|---------------------------------------------------------------------------------------------------|
| Moshiri and Daneshmand (2020) | Iran                      | 1976–2014 | ARDL     | No impact on environmental quality                                                                |
| Zhang et al. (2017)           | Pakistan                  | 1985–2018 | DARDL    | increases CO <sub>2</sub>                                                                         |
| Fan et al. (2022)             | 286 Cities in China       | 2007–2017 | GMM      | Environmental quality increases                                                                   |
| Aydin et al. (2023)           | European Union            | 1995–2018 | CS-ARDL  | Mixed Results                                                                                     |
| Ahmad et al. (2023)           | G-11                      | 2000–2018 | CS-ARDL  | Lowens EFP                                                                                        |
| Alakbarov et al. (2024)       | G-20                      | 1992–2014 | ARDL     | increases CO <sub>2</sub>                                                                         |
| Nguyen (2024)                 | Southeast Asian countries | 1990–2019 | ARDL     | Lowens CO <sub>2</sub>                                                                            |
| Bozatl and Akca (2024)        | Netherlands               | 1996–2021 | ARDL     | Environmental quality degrades                                                                    |
| Sogut et al. (2025)           | European Union            | 1996–2020 | RCCE-CCE | Economic growth initially degrades environmental quality. Later it improves environmental quality |
| Nordin et al. (2025)          | ASEAN                     | 1995–2019 | CCEMG    | Economic growth initially degrades environmental quality. Later it improves environmental quality |

**Table 4**

Description of variables.

| Variables                                        | Abbreviation | Description                          | Source            |
|--------------------------------------------------|--------------|--------------------------------------|-------------------|
| Greenhouse Gas Emissions from Agriculture        | GHG          | Per Capita                           | Our World in Data |
| Gross Domestic Product                           | GDP          | Per Capita (2015 \$ constant Prices) | WDI               |
| Total Budgetary Support Estimate for Agriculture | TBS          | %GDP                                 | OECD              |
| Financial Development                            | FD           | Index                                | IMF               |
| Financial Institutions                           | FI           | Index                                | IMF               |
| Financial Markets                                | FM           | Index                                | IMF               |

**Table 4.**

The model considered within the scope of the research is as follows:

$$GHG_{i,t} = \beta_0 + \beta_1 TBS_{i,t} + \beta_2 GDP_{i,t} + \beta_3 FD_{i,t} + \varepsilon_{it} \quad (1)$$

The dependent variable in the research models is agricultural GHG emissions.  $\beta_0$  and  $\varepsilon_{it}$  denote constant and error term, respectively. The analysis process is carried out by taking the logarithm of all variables. In the model, the role of financial development is analyzed on the basis of agricultural policies and economic growth. Thus, it is aimed to reveal the extent to which financial development dynamics are effective in reducing GHG emissions, which are theoretically expected to increase due to agricultural support policies and economic growth.

In order to analyses these relationships, the up-to-date panel time series methodology will be used. Accordingly, the first step involves diagnostic tests for cross-section dependence (CSD) and slope homogeneity. Because, if there is CSD and heterogeneity of slope coefficients, it is important to select appropriate methods in terms of reliable results. In this context, CSD on the model basis is investigated using Breusch and Pagan's (1980) CDLM1 and Pesaran's (2015) CDLM2 and CD tests. Then, the Pesaran and Yamagata (2008) delta test based on the Swamy

(1970) test is used to investigate whether the slope coefficients are homogeneous.

In the second stage, the degree of cointegration of the series will be determined with the [Breitung and Das \(2005\)](#) unit root test, which is based on robust standard errors in the presence of CSD and produces reliable results for small samples. In the third stage, the validity of the long-run relationship is investigated with the [Westerlund and Edgerton \(2007\)](#) LM bootstrap panel cointegration method, which extends the [McCoskey and Kao \(1998\)](#) methodology using a bootstrap scheme. This test, which uses LM statistics, produces reliable results both under CSD in the models and in small samples thanks to the bootstrap method. In the last stage, the AMG estimator developed by [Eberhardt and Bond \(2009\)](#) and [Eberhardt and Teal \(2010\)](#) is used to calculate long-run coefficients on both panel and country basis. In this method, it is possible to model unobservable common factors by using the common dynamic effect parameter in unit-specific regressions. In addition, its robustness to CSD and parameter heterogeneity makes the estimator reliable ([Bozatlı & Akca, 2023](#)).

Finally, the impact of the components of financial development is also controlled in order to obtain robust results. This is because financial development is divided into two subcomponents: financial institutions and financial markets. These two sub-components are calculated according to the depth, access and efficiency criteria and ultimately constitute the financial development index. Therefore, since each country has its own financial institutions and markets, it is likely to have different effects. In this context, by including financial institutions and financial markets variables instead of financial development in the model in equation (1), it is planned to reveal the extent to which financial development dynamics are effective and to obtain robustness results.

#### 4. Empirical results

In the first step of the empirical analysis, CSD and homogeneity of the coefficients are tested and the findings are reported in [Table 5](#).

The findings in [Table 5](#) imply the existence of CSD and heterogeneity of slope coefficients within the scope of the model considered. Accordingly, taking these conditions into account in the following stages of the empirical analysis process is essential for reliable results. [Table 6](#) presents the results of the [Breitung and Das \(2005\)](#) unit root test that takes into account CSD.

The results of the unit root test by [Breitung and Das \(2005\)](#) show that all variables are stationary at first difference. Therefore, since analyses with the level values of the series would lead to spurious regression results, cointegration methodology can be used. According to the unit

**Table 5**  
Cross-section dependency and homogeneity checks.

| Cross-Section<br>Dependency | CD <sub>LM1</sub>    | CD <sub>LM2</sub>      | CD                 |
|-----------------------------|----------------------|------------------------|--------------------|
| GHG = f (TBS, GDP, FD)      | 194.559*<br>(0.000)  | 32.782*<br>(0.000)     | 13.724*<br>(0.000) |
| GHG = f (TBS, GDP, FI)      | 229.929*<br>(0.000)  | 39.240*<br>(0.000)     | 15.004*<br>(0.000) |
| GHG = f (TBS, GDP, FM)      | 108.314*<br>(0.000)  | 17.036*<br>(0.000)     | 2.372**<br>(0.017) |
| <b>Slope Homogeneity</b>    | <b>Test</b>          | <b>Test Statistics</b> | <b>P-value</b>     |
| GHG = f (TBS, GDP, FD)      | $\hat{\Delta}$       | 7.090*                 | 0.000              |
|                             | $\hat{\Delta}_{adj}$ | 8.065*                 | 0.000              |
| GHG = f (TBS, GDP, FI)      | $\hat{\Delta}$       | 7.809*                 | 0.000              |
|                             | $\hat{\Delta}_{adj}$ | 8.884*                 | 0.000              |
| GHG = f (TBS, GDP, FM)      | $\hat{\Delta}$       | 5.777*                 | 0.000              |
|                             | $\hat{\Delta}_{adj}$ | 6.572*                 | 0.000              |

**Note:** \* and \*\* implies that the null hypothesis is rejected at the 1% and 5% significance levels, respectively. Values in parentheses indicate probability values.

**Table 6**  
Unit root results.

| Variables | I (0)           | I (1)             |
|-----------|-----------------|-------------------|
| GHG       | 0.4616 (0.6678) | −2.4818 (0.0065)* |
| TBS       | 0.4968 (0.6903) | −3.0790 (0.0010)* |
| GDP       | 1.4242 (0.9228) | −3.2717 (0.0005)* |
| FD        | 1.3071 (0.9044) | −3.0419 (0.0012)* |
| FI        | 0.7414 (0.7708) | −3.2688 (0.0005)* |
| FM        | 0.1861 (0.5738) | −3.0089 (0.0013)* |

**Note:** \* denote rejection of the null hypothesis at 1% significance level. Probabilities are in parentheses.

root test results, the a priori condition of [Westerlund and Edgerton \(2007\)](#) LM bootstrap panel cointegration methodology, that all variables are I (1), is satisfied. In addition, given that it produces effective results under CSD and in small samples, this method is utilized to question the validity of the long-run relationship. Findings regarding cointegration test results are reported in [Table 7](#).

The presence of CSD is an important criterion in evaluating the results of the LM Bootstrap cointegration test. If there is no CSD, asymptotic probability values are taken into account; otherwise, bootstrap critical values are relied upon. Accordingly, the null hypothesis implying cointegration relationship cannot be rejected for the related models. In other words, the cointegration relationship is valid for the relevant models and there is no obstacle in calculating the long-run coefficients. In this context, the long-run coefficients for the model presented in equation (1) are reported in [Table 8](#) using the AMG estimator.

Regarding the findings in [Tables 8](#) and it is possible to say that only economic growth increases agricultural GHG emissions on a panel basis. Financial development and agricultural support policies do not have a statistically significant effect on a panel basis. However, when country-based results are analyzed, it is noteworthy that there are different results. Contrary to the panel-based results, agricultural support policies increase agricultural GHG emissions in China and Türkiye. On the other hand, similar to the panel-based results, financial development does not have a significant effect in most countries. However, financial development policies have a decreasing role on agricultural GHG emissions in South Africa and Türkiye. Finally, in terms of economic growth, in all countries except Brazil and Russia, economic growth or an increase in economic welfare encourages agricultural GHG. Such results reveal the importance of country-specific dynamics in the assessment of agricultural policies and GHG emissions.

##### 4.1. Robustness check

[Tables 9 and 10](#) show the effects of financial institutions and financial markets on agricultural GHG, respectively.

The findings in [Table 9](#) show that financial institutions, which are components of financial development, mostly lead to similar effects to financial development. While none of the variables have a statistically significant effect on a panel basis, heterogeneous country-specific results are noteworthy. For example, while financial institutions have an increasing effect on agricultural GHG in Brazil and India, the opposite result is observed in South Africa and Türkiye. Again, economic growth has a positive effect on agricultural GHG in China, South Africa and

**Table 7**  
Results of the LM bootstrap cointegration test.

| Model                  | Test<br>Statistic | Asymptotic p-value | Bootstrap p-value |
|------------------------|-------------------|--------------------|-------------------|
| GHG = f (TBS, GDP, FD) | 2.049             | 0.020              | 0.907*            |
| GHG = f (TBS, GDP, FI) | 2.034             | 0.021              | 0.925*            |
| GHG = f (TBS, GDP, FM) | 2.418             | 0.008              | 0.815*            |

**Notes:** \* implies that the null hypothesis cannot be rejected at the 1% significance level. The bootstrap is based on 1000 replications.

**Table 8**  
AMG estimation results.

| Countries    | TBS    | GDP      | FD       |
|--------------|--------|----------|----------|
| Brazil       | 0.034  | −0.070   | 0.521*   |
| China        | 0.148* | 0.263*   | −0.008   |
| India        | 0.050  | 0.063*   | 0.054    |
| Russia       | 0.019  | 0.028    | −0.038   |
| South Africa | −0.138 | 0.345*** | −0.815*  |
| Türkiye      | 0.124* | 0.857*   | −0.537** |
| Panel        | 0.039  | 0.247*** | −0.137   |

**Note:** \*, \*\* and \*\*\* imply statistical significance at the 1%, 5%, and 10% levels, respectively.

**Table 9**  
Impact of financial institutions.

| Countries    | TBS      | GDP      | FI      |
|--------------|----------|----------|---------|
| Brazil       | −0.048   | −0.273   | 0.801*  |
| China        | 0.136**  | 0.218*   | −0.034  |
| India        | 0.008    | −0.096** | 0.311*  |
| Russia       | 0.016    | −0.017   | 0.055   |
| South Africa | −0.046   | 0.819*   | −0.963* |
| Türkiye      | 0.073*** | 0.807*   | −0.241* |
| Panel        | 0.023    | 0.243    | −0.011  |

**Note:** \*, \*\* and \*\*\* imply statistical significance at the 1%, 5%, and 10% levels, respectively.

**Table 10**  
Impact of financial markets.

| Countries    | TBS      | GDP      | FM        |
|--------------|----------|----------|-----------|
| Brazil       | 0.024    | 0.230    | 0.165     |
| China        | 0.155*   | 0.209    | 0.019     |
| India        | 0.057*** | 0.048*   | 0.005     |
| Russia       | 0.016    | 0.003    | −0.028    |
| South Africa | 0.005    | −0.087   | −0.292*** |
| Türkiye      | 0.117**  | 0.544*   | 0.472     |
| Panel        | 0.062**  | 0.157*** | 0.057     |

**Note:** \*, \*\* and \*\*\* imply statistical significance at the 1%, 5%, and 10% levels, respectively.

Türkiye, while it has a negative effect in India. Finally, agricultural support policies have an increasing effect on agricultural GHG only in China and Türkiye. Such results are mostly consistent with and confirm the effects of financial development obtained in Table 8.

When the results in Table 10, which take into account the role of financial markets, are analyzed, it is noteworthy that there are some different relationships. On a panel basis, both economic growth and agricultural supports have a favorable effect on GHG. In terms of the impact of financial markets, only in South Africa, there is a mitigating effect on agricultural GHG. Regarding both agricultural subsidies and economic growth, a positive relationship is found only in Türkiye and India. There is no statistically significant relationship for other countries.

Considering all together, it is possible to draw the following inferences relatively: Agricultural supports have a GHG-boosting effect in China and Türkiye. No statistically significant effect was found for other countries and panel-basis in terms of agricultural supports. Regarding economic growth, a positive relationship was found both on a panel basis and on a country basis (Türkiye, South Africa, India and China). In fact, at least two model estimation results support this argument. Finally, the agricultural GHG-reducing effect of financial development is confirmed only for Türkiye and South Africa. On the contrary, in Brazil, financial development plays an improving role in agricultural GHG. For the remaining countries, statistically significant and sufficient evidence could not be obtained.

## 4.2. Discussion of key findings

This study examines the impact of agricultural budgetary support, economic growth, and financial development on agricultural GHG emissions in BRICS-T countries for the period 2000–2021. The results of the main model indicate that agricultural subsidies have increased emissions in China and Türkiye. Additionally, GDP has contributed to higher emissions in China, India, South Africa, Türkiye, and across the panel, whereas financial development has led to increased emissions in Brazil but has played a mitigating role in Türkiye and South Africa.

The increase in emissions due to agricultural subsidies in China and Türkiye suggests that these support mechanisms have facilitated intensive agricultural expansion without sufficiently integrating environmental considerations. In China, large-scale mechanization and industrialized farming practices have likely contributed to this trend. Similarly, in Türkiye, the rapid urbanization process and shifting rural demographics have led to agricultural support being directed towards productivity-enhancing measures, which, while beneficial for food security, may have unintended environmental consequences. However, Türkiye presents a unique case within the BRICS-T group, as financial institutions have played a role in offsetting the negative environmental effects of agricultural expansion. Türkiye has increasingly emphasized sustainable agricultural practices through financial regulations and incentive programs, including green financing mechanisms and targeted subsidies for eco-friendly farming. These developments indicate that financial institutions in Türkiye have facilitated access to sustainable agricultural investments, thereby helping to counteract some of the adverse environmental impacts associated with traditional agricultural subsidies.

Regarding financial development, the findings indicate a divergent impact across BRICS-T countries. In Brazil, financial development has exacerbated agricultural emissions, potentially due to increased access to capital for resource-intensive agricultural activities. In contrast, Türkiye and South Africa have benefitted from financial development in mitigating emissions, particularly through the role of financial institutions. Robustness checks reveal that in Türkiye, the emission-reducing effect of financial development is primarily driven by financial institutions rather than financial markets. This suggests that financial institutions in Türkiye have successfully facilitated investments in sustainable agricultural practices, supporting the adoption of eco-friendly farming technologies and improved resource management. Strengthening such institutional mechanisms in other BRICS-T countries could offer a viable pathway toward reducing agricultural emissions without compromising economic development.

## 5. Conclusion and policy recommendation

Agriculture is both a significant contributor to and a victim of climate change. As agricultural activities expand to meet the growing global food demand, they also drive considerable CO<sub>2</sub> emissions through land-use changes, deforestation, and energy-intensive farming practices (Zhang et al., 2025). Governments have implemented various agricultural support policies to mitigate these environmental externalities while ensuring food security and rural development. However, these public policies may cause an unbalanced increase in agricultural production and environmental pollution (Stamoulis & Zezza, 2003). In addition, agricultural support policies can shape the environmental consequences of economic growth, and financial development (financial markets and financial institutions) that have the potential to directly affect agricultural production.

Theoretical frameworks suggest multiple channels through which agricultural support policies can impact CO<sub>2</sub> emissions. On one hand, subsidies and financial incentives may encourage the adoption of modern, low-carbon technologies, leading to increased efficiency and reduced emissions. On the other hand, excessive subsidies, particularly in fossil-fuel-dependent agricultural practices, may exacerbate carbon

emissions by reinforcing environmentally unsustainable production methods (Biffi et al., 2021; Ke & Huang, 2024; Saman, 2021). Financial development can further influence this complex relationship by facilitating investment in sustainable technologies or encouraging capital-intensive, high-emission agricultural expansion. Similarly, markets can promote efficiency and sustainability, whereas market failures may lead to resource misallocation.

Considering these theoretical foundations, this study investigates the impact of agricultural support policies on agricultural GHG emissions in BRICS-T countries, explicitly considering the moderating roles of financial development, markets, and institutions. To obtain robust findings, we first used a main model that included the FD variable and then a second model that included the sub-indicators of FD separately. This multi-model approach allows us to discern whether a given factor independently influences emissions or whether its effect emerges only when interacting with other variables. In this context, this study aims to determine the real drivers of agricultural GHG emissions and make concrete policy recommendations by considering the interdependencies among these factors. Various models have been used in the literature to examine the relationship between these factors and environmental indicators (ecological footprint, emissions, etc.). However, no study has been found to determine the environmental effects of these factors in the agricultural field. In addition, these studies have not examined these dimensions comprehensively, especially in the context of emerging economies such as the BRICS-T countries, where rapid agricultural expansion and institutional diversification pose several challenges and opportunities. Our study fills this gap, providing empirical evidence on the conditions under which support mechanisms can effectively reduce or increase agricultural GHG emissions, providing implications for sustainable agricultural policy.

### 5.1. Policy recommendation

Given the heterogeneity in findings across BRICS-T countries, policy recommendations should be tailored to the specific economic and institutional contexts of each nation. In China and Türkiye, where agricultural subsidies have contributed to increased emissions, it is imperative to redesign subsidy mechanisms to prioritize environmentally sustainable agricultural practices. Instead of broadly supporting agricultural expansion, subsidies should be allocated toward precision agriculture technologies, soil conservation programs, and low-emission farming techniques. Moreover, stricter environmental conditions should be attached to agricultural financial support to ensure that subsidies do not inadvertently contribute to further environmental degradation.

The finding that GDP has led to increased agricultural emissions across China, India, South Africa, Türkiye, and the panel suggests that BRICS-T countries should integrate sustainability into their economic growth strategies. Given their historical focus on rapid economic expansion, these countries should transition towards policies that emphasize green economic transformation. Integrating carbon pricing mechanisms into agricultural production could help mitigate the environmental impact of economic growth. Additionally, international cooperation within BRICS-T could facilitate the exchange of best practices and technological innovations in sustainable farming, fostering a coordinated approach to agricultural emissions reduction.

Türkiye and South Africa stand out as cases where financial development, particularly through financial institutions, has played a role in reducing agricultural emissions. Expanding financial products such as green bonds and loans could further enhance the role of financial institutions in promoting sustainable agriculture. On the other hand, the results regarding FD show that banks and other financial institutions should also consider environmental risks when providing agricultural loans. In this way, FD can continue to contribute positively to agricultural emission reduction. Overall, the findings suggest that a policy approach that includes agricultural subsidies, economic growth strategies, and financial development in a way that prioritizes environmental

sustainability is needed. By aligning financial incentives, regulatory mechanisms, and international cooperation, BRICS-T countries can work toward reducing agricultural emissions while maintaining economic development and food security.

### 5.2. Limitations and future studies

This study provides important findings on the relationship between agricultural policies, financial development, and GHG emissions in BRICS-T countries. However, some limitations should be acknowledged. The availability and consistency of agricultural emissions data vary across countries, potentially affecting the precision of the results. Our study considered GHG data, including seven critical pollutants. Empirical results may change when considering specific pollutants such as CO<sub>2</sub> or methane. In addition, this study examines aggregate agricultural GHG emissions, but different agricultural subsectors (e.g., crop production) may exhibit varying emissions. Further research should investigate sector-specific effects to develop more specific policy recommendations. Finally, our study does not take into account the interaction of all variables. Therefore, the same variable may have different effects in another model. Future studies can obtain methodologically robust results by including different methods.

### CRediT authorship contribution statement

**Ahmet Bagci:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing, Supervision. **Yasin Sogut:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing, Data collection. **Oguzhan Bozatli:** Investigation, Methodology, Software, Formal analysis, Writing – original draft, Writing – review & editing. **Tunahan Degirmenci:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing.

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### Data availability

The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

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### Abbreviations

Augmented Mean Group: AMG  
Carbon Dioxide: CO<sub>2</sub>  
Cross-Section Dependence: CSD  
Greenhouse Gas: GHG  
Gross Domestic Product: GDP

### References

- Adebayo, T. S., Alola, A. A., Ullah, S., & Abbas, S. (2024). The growth impacts of agriculture value-added, energy utilization, and environmental degradation in Pakistan: Causality in continuous wavelet transform approach. May. In *Natural resources forum* (Vol. 48, pp. 343–363). Oxford, UK: Blackwell Publishing Ltd. <https://doi.org/10.1111/1477-8947.12306>, 2.
- Ahmad, M., Dai, J., Mehmood, U., & Abou Houran, M. (2023). Renewable energy transition, resource richness, economic growth, and environmental quality: Assessing the role of financial globalization. *Renewable Energy*, 216, Article 119000. <https://doi.org/10.1016/j.renene.2023.119000>

- Akca, H. (2021). Environmental Kuznets Curve and financial development in Türkiye: Evidence from augmented ARDL approach. *Environmental Science and Pollution Research*, 28(48), 69149–69159. <https://doi.org/10.1007/s11356-021-15417-w>
- Alakbarov, N., Gündüz, M., & Şaşmaz, M.Ü. (2024). Exploring the link between economic growth, energy consumption, and environmental pollution in G20. In *Natural resources forum*. Oxford, UK: Blackwell Publishing Ltd. <https://doi.org/10.1111/1477-8947.12440>
- Aljadani, A., Toumi, H., & Hsini, M. (2023). Exploring the interactive effects of environmental quality and financial development in top ten remittance-receiving countries: Do technological effect matter? *Environmental Science and Pollution Research*, 30(19), 56930–56945. <https://doi.org/10.1007/s11356-023-26256-2>
- Anwar, A., Sinha, A., Sharif, A., Siddique, M., Irshad, S., Anwar, W., & Malik, S. (2022). The nexus between urbanization, renewable energy consumption, financial development, and CO<sub>2</sub> emissions: Evidence from selected Asian countries. *Environment, Development and Sustainability*, 24(5), 6556–6576. <https://doi.org/10.1007/s10668-021-01716-2>
- Appiah, K., Du, J., & Poku, J. (2018). Causal relationship between agricultural production and carbon dioxide emissions in selected emerging economies. *Environmental Science and Pollution Research*, 25, 24764–24777.
- Aydin, M., Sogut, Y., & Altundemir, M. E. (2023). Moving toward the sustainable environment of European Union countries: Investigating the effect of natural resources and green budgeting on environmental quality. *Resources Policy*, 83, Article 103737. <https://doi.org/10.1016/j.resourpol.2023.103737>
- Aytun, C., Erdogan, S., Pata, U. K., & Cengiz, O. (2024). Associating environmental quality, human capital, financial development and technological innovation in 19 middle-income countries: A disaggregated ecological footprint approach. *Technology in Society*, 76, Article 102445. <https://doi.org/10.1016/j.techsoc.2023.102445>
- Aziz, G., Sarwar, S., Waheed, R., & Khan, M. S. (2024). The significance of renewable energy, globalization, and agriculture on sustainable economic growth and green environment: Metaphorically, a two-sided blade. August. In *Natural resources forum* (Vol. 48, pp. 763–783). Oxford, UK: Blackwell Publishing Ltd. <https://doi.org/10.1111/1477-8947.12326>, 3.
- Balogh, J. M. (2022). The impacts of agricultural development and trade on CO<sub>2</sub> emissions? Evidence from the non-European union countries. *Environmental Science & Policy*, 137, 99–108. <https://doi.org/10.1016/j.envsci.2022.08.012>
- Balogh, J. M., & Jámor, A. (2020). The environmental impacts of agricultural trade: A systematic literature review. *Sustainability*, 12(3), 1152. <https://doi.org/10.3390/su12031152>
- Bas, T., Kara, F., & Alola, A. A. (2021). The environmental aspects of agriculture, merchandize, share, and export value-added calibrations in Türkiye. *Environmental Science and Pollution Research*, 28(44), 62677–62689.
- Biffi, S., Traldi, R., Crezee, B., Beckmann, M., Egli, L., Schmidt, D. E., ... Ziv, G. (2021). Aligning agri-environmental subsidies and environmental needs: A comparative analysis between the US and EU. *Environmental Research Letters*, 16(5), Article 054067. <https://doi.org/10.1088/1748-9326/abfa4e>
- Bozatli, O., & Akca, H. (2023). The effects of environmental taxes, renewable energy consumption and environmental technology on the ecological footprint: Evidence from advanced panel data analysis. *Journal of Environmental Management*, 345, Article 118857. <https://doi.org/10.1016/j.jenvman.2023.118857>
- Bozatli, O., & Akca, H. (2024). Effectiveness of environmental protection expenditures and resource tax policy in the Netherlands' load capacity factor: Do government effectiveness and renewable energy matter? Evidence from fourier augmented ARDL. *Resources Policy*, 92, Article 105030. <https://doi.org/10.1016/j.resourpol.2024.105030>
- Breitung, J., & Das, S. (2005). Panel unit root tests under cross-sectional dependence. *Statistica Neerlandica*, 59(4), 414–433. <https://doi.org/10.1111/j.1467-9574.2005.00299.x>
- Breusch, T. S., & Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. *The Review of Economic Studies*, 47(1), 239–253. <https://doi.org/10.2307/2297111>
- Cillis, D., Maestrini, B., Pezzuolo, A., Marinello, F., & Sartori, L. (2018). Modeling soil organic carbon and carbon dioxide emissions in different tillage systems supported by precision agriculture technologies under current climatic conditions. *Soil and Tillage Research*, 183, 51–59. <https://doi.org/10.1016/j.still.2018.06.001>
- Doğan, N. (2019). The impact of agriculture on CO<sub>2</sub> emissions in China. *Panoeconomicus*, 66(2), 257–271. <https://doi.org/10.2298/PAN160504030D>
- Eberhardt, M., & Bond, S. (2009). *Cross-section dependence in nonstationary panel models: A novel estimator*. Munich Personal RePEc Archive, 17692 <https://mpira.ub.uni-muenchen.de/17870/>.
- Eberhardt, M., & Teal, F. (2010). *Productivity analysis in global manufacturing production*. University of Oxford. <https://ora.ox.ac.uk/objects/uuid:ea831625-9014-40ec-acb5-516ecfbd2118>
- Fakher, H. A., Ahmed, Z., Alvarado, R., & Murshed, M. (2022). Exploring renewable energy, financial development, environmental quality, and economic growth nexus: New evidence from composite indices for environmental quality and financial development. *Environmental Science and Pollution Research*, 29(46), 70305–70322. <https://doi.org/10.1007/s11356-022-20709-w>
- Fan, W., Yan, L., Chen, B., Ding, W., & Wang, P. (2022). Environmental governance effects of local environmental protection expenditure in China. *Resources Policy*, 77, Article 102760. <https://doi.org/10.1016/j.resourpol.2022.102760>
- Fatima, N., Xuhua, H., Khan, M. K., & Dagar, V. (2025). Sustainability with environmental policy stringency and financial development for green technological innovations: Evidence from Sub-Saharan Africa. *Journal of Environmental Management*, 373, Article 123429. <https://doi.org/10.1016/j.jenvman.2024.123429>
- Habiba, U., & Xinbang, C. (2022). The impact of financial development on CO<sub>2</sub> emissions: New evidence from developed and emerging countries. *Environmental Science and Pollution Research*, 29(21), 31453–31466. <https://doi.org/10.1007/s11356-022-18533-3>
- Iyke-Ofoedu, M. I., Takon, S. M., Ugwunta, D. O., Ezeaku, H. C., Nsofor, E. S., & Egbo, O. P. (2024). Impact of CO<sub>2</sub> emissions embodied in the agricultural sector on carbon sequestration in South Africa: The role of environmental taxes and technological innovation. *Journal of Cleaner Production*, 444, Article 141210. <https://doi.org/10.1016/j.jclepro.2024.141210>
- Kara, F., Bas, T., Tirmandioglu Talu, N. H., & Alola, A. A. (2021). Investigating the carbon emission aspects of agricultural land utilization in Türkiye. *Integrated Environmental Assessment and Management*, 18(4), 988–996.
- Ke, C., & Huang, S. Z. (2024). The effect of environmental regulation and green subsidies on agricultural low-carbon production behavior: A survey of new agricultural management entities in Guangdong Province. *Environmental Research*, 242, Article 117768. <https://doi.org/10.1016/j.envres.2023.117768>
- Khan, M., & Ozturk, I. (2021). Examining the direct and indirect effects of financial development on CO<sub>2</sub> emissions for 88 developing countries. *Journal of Environmental Management*, 293, Article 112812. <https://doi.org/10.1016/j.jenvman.2021.112812>
- Kirikaleli, D., & Adebayo, T. S. (2021). Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence. *Sustainable Development*, 29(4), 583–594. <https://doi.org/10.1002/sd.2159>
- Lacombe, C., Couix, N., & Hazard, L. (2018). Designing agroecological farming systems with farmers: A review. *Agricultural Systems*, 165, 208–220. <https://doi.org/10.1016/j.agsy.2018.06.014>
- Li, L., Awada, T., Shi, Y., Jin, V. L., & Kaiser, M. (2025). Global greenhouse gas emissions from agriculture: Pathways to sustainable reductions. *Global Change Biology*, 31(1), Article e70015. <https://doi.org/10.1111/gcb.70015>
- Ma, B., Karimi, M. S., Mohammed, K. S., Shahzadi, I., & Dai, J. (2024). Nexus between climate change, agricultural output, fertilizer use, agriculture soil emissions: Novel implications in the context of environmental management. *Journal of Cleaner Production*, 450, Article 141801. <https://doi.org/10.1016/j.jclepro.2024.141801>
- McCoskey, S., & Kao, C. (1998). A residual-based test of the null of cointegration in panel data. *Econometric Reviews*, 17(1), 57–84. <https://doi.org/10.1080/07474939808800403>
- Moshiri, S., & Daneshmand, A. (2020). How effective is government spending on environmental protection in a developing country? An empirical evidence from Iran. *Journal of Economic Studies*, 47(4), 789–803. <https://doi.org/10.1108/JES-12-2018-0458>
- Nguyen, Q. H. (2024). The influence of key economic globalization factors on economic growth and environmental quality: An empirical study in Southeast Asian countries. *The Journal of International Trade & Economic Development*, 33(1), 57–75.
- Nordin, S. K. S., Hamzah, K., Khashi'ie, N. S., Zainal, N. A., & Halim, B. A. (2025). Testing environmental Kuznets Curve (EKC) hypothesis in ASEAN countries: Evidence based on STIRPAT framework with cross-sectional dependency. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 46(2), 227–238. <https://doi.org/10.37934/araset.46.2.227238>
- Oanh, T. T. K. (2024). Digital financial inclusion in the context of financial development: Environmental destruction or the driving force for technological advancement. *Borsa Istanbul Review*, 24(2), 292–303. <https://doi.org/10.1016/j.bir.2024.01.003>
- Pata, U. K. (2021). Linking renewable energy, globalization, agriculture, CO<sub>2</sub> emissions and ecological footprint in BRIC countries: A sustainability perspective. *Renewable Energy*, 173, 197–208. <https://doi.org/10.1016/j.renene.2021.03.125>
- Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews*, 34(6–10), 1089–1117. <https://doi.org/10.1080/07474938.2014.956623>
- Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics*, 142(1), 50–93. <https://doi.org/10.1016/j.jeconom.2007.05.010>
- Raihan, A. (2023). An econometric evaluation of the effects of economic growth, energy use, and agricultural value added on carbon dioxide emissions in Vietnam. *Asia-Pacific Journal of Regional Science*, 7(3), 665–696. <https://doi.org/10.1007/s41685-023-00278-7>
- Raihan, A., & Tuspekova, A. (2022). Nexus between economic growth, energy use, agricultural productivity, and carbon dioxide emissions: New evidence from Nepal. *Energy Nexus*, 7, Article 100113. <https://doi.org/10.1016/j.nexus.2022.100113>
- Rehman, A., Alam, M. M., Alvarado, R., İşik, C., Ahmad, F., Cismas, L. M., & Pupazan, M. C. M. (2022). Carbonization and agricultural productivity in Bhutan: Investigating the impact of crops production, fertilizer usage, and employment on CO<sub>2</sub> emissions. *Journal of Cleaner Production*, 375, Article 134178. <https://doi.org/10.1016/j.jclepro.2022.134178>
- Saman, C. (2021). Does agricultural subsidies in the EU improved environmental outcomes. *Transformations in Business and Economics*, 20(3), 642–652.
- Shahbaz, M., Aydin, M., Degirmenci, T., & Bozatli, O. (2024). The role of agriculture-forestry-fisheries sectors, biodiversity expenditures, and renewable energy on environmental quality for The Netherlands: Evidence from novel Fourier ARDL. In *Natural resources forum*. Oxford, UK: Blackwell Publishing Ltd. <https://doi.org/10.1111/1477-8947.12517>
- Shahbaz, M., Destek, M. A., Dong, K., & Jiao, Z. (2021). Time-varying impact of financial development on carbon emissions in G-7 countries: Evidence from the long history. *Technological Forecasting and Social Change*, 171, Article 120966. <https://doi.org/10.1016/j.techfore.2021.120966>
- Sogut, Y., Demirtas, N., Teksan, E., Torusdag, M., Inal, V., & Aydin, M. (2025). Building a sustainable environment in EU countries: The critical role of infrastructure investments and institutional quality. *The International Journal of Sustainable Development and World Ecology*, 32(1), 96–109.
- Stamoulis, K. G., & Zezza, A. (2003). A conceptual framework for national agricultural, rural development, and food security strategies and policies. *Food and Agriculture*

- Organization of the United Nations. Agricultural and Development Economics Division. ESA Working Paper No. 03-17; 2003.
- Sun, B., Wang, X., Luo, P., Zhao, Y., & Rijal, M. (2024). Importance of farmers' awareness on ecological revitalization to promote sustainable development. *Sustainability*, 16 (22), Article 10134. <https://doi.org/10.3390/su162210134>
- Swamy, P. A. (1970). Efficient inference in a random coefficient regression model. *Econometrica: Journal of the Econometric Society*, 311–323. <https://doi.org/10.2307/1913012>
- Tongwane, M. I., Moeletsi, M. E., & Tsubo, M. (2020). Trends of carbon emissions from applications of nitrogen fertiliser and crop residues to agricultural soils in South Africa. *Journal of Environmental Management*, 272, Article 111056. <https://doi.org/10.1016/j.jenvman.2020.111056>
- Usman, M., Jahanger, A., Makhdom, M. S. A., Radulescu, M., Balsalobre-Lorente, D., & Jianu, E. (2022). An empirical investigation of ecological footprint using nuclear energy, industrialization, fossil fuels and foreign direct investment. *Energies*, 15(17), 6442.
- Wahab, S., Imran, M., Ahmed, B., Rahim, S., & Hassan, T. (2024). Navigating environmental concerns: Unveiling the role of economic growth, trade, resources and institutional quality on greenhouse gas emissions in OECD countries. *Journal of Cleaner Production*, 434, Article 139851. <https://doi.org/10.1016/j.jclepro.2023.139851>
- Westerlund, J., & Edgerton, D. L. (2007). A panel bootstrap cointegration test. *Economics Letters*, 97(3), 185–190. <https://doi.org/10.1016/j.econlet.2007.03.003>
- Xiong, C., Yang, D., Huo, J., & Zhao, Y. (2016). The relationship between agricultural carbon emissions and agricultural economic growth and policy recommendations of a low-carbon agriculture economy. *Polish Journal of Environmental Studies*, 25(5), 2187–2195. <https://doi.org/10.15244/pjoes/63038>
- Xu, D., Sheraz, M., Hassan, A., Sinha, A., & Ullah, S. (2022). Financial development, renewable energy and CO2 emission in G7 countries: New evidence from non-linear and asymmetric analysis. *Energy Economics*, 109, Article 105994. <https://doi.org/10.1016/j.eneco.2022.105994>
- Xuezhou, W., Manu, E. K., & Akowuah, I. N. (2022). Financial development and environmental quality: The role of economic growth among the regional economies of sub-Saharan Africa. *Environmental Science & Pollution Research*, 29(16), 23069–23093. <https://doi.org/10.1007/s11356-021-17271-2>
- Yurtkuran, S. (2021). The effect of agriculture, renewable energy production, and globalization on CO2 emissions in Türkiye: A bootstrap ARDL approach. *Renewable Energy*, 171, 1236–1245. <https://doi.org/10.1016/j.renene.2021.03.009>
- Zhang, K., Chen, Z., & Wang, Y. (2025). A novel approach for agricultural carbon emission reduction by integrating fermatean neutrosophic set with WINGS and AHP-EWM. *Scientific Reports*, 15(1), 391. <https://doi.org/10.1038/s41598-024-84423-y>
- Zhang, G., Xiao, X., Biradar, C. M., Dong, J., Qin, Y., Menarguez, M. A., ... Moore III, B. (2017). Spatiotemporal patterns of paddy rice croplands in China and India from 2000 to 2015. *Science of the Total Environment*, 579, 82–92. <https://doi.org/10.1016/j.scitotenv.2016.10.223>