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How CO_2 Emissions and Agriculture Shape Economic Growth: Evidence from OECD Countries

Son Lam Nguyen , *Anh Hong Thi Nguyen* * , *Hop Van Vo*

School of Finance and Accounting, Industrial University of Ho Chi Minh City, Ho Chi Minh City 70000, Vietnam

ABSTRACT

This study analyzes the impact of agriculture and CO_2 emissions on economic growth in OECD countries over more than two decades from 2000 to 2023. Using the two-step SGMM estimation method, the results show that agriculture positively influences economic growth in both the short and long run, with GDP increasing by 0.225% and 0.532%, respectively, as agricultural output rises. Additionally, CO_2 emissions also have a positive effect on economic growth, reflecting the crucial role of industries in driving GDP. However, in the long run, uncontrolled emissions may harm the environment and increase economic costs. Furthermore, trade openness is found to be a growth-enhancing factor, while energy consumption negatively affects economic growth, highlighting the need for improved energy efficiency and a transition to renewable energy sources. In addition, when analyzing the data by region, the results show that OECD member countries in the European region have reduced CO_2 emissions more strongly than the Americas and Asia-Oceania regions, while the economic development of the Americas and Asia-Oceania regions depends on agriculture since the Covid 19 pandemic or agriculture contributes more to economic growth than in member countries in the European region. The study suggests policies such as applying advanced technologies in agriculture, imposing carbon taxes, and increasing investment in renewable energy to achieve sustainable economic growth in OECD countries.

Keywords: Agriculture; CO_2 Emissions; Economic Growth; OECD; SGMM

*CORRESPONDING AUTHOR:
Anh Hong Thi Nguyen, School of Finance and Accounting, Industrial University of Ho Chi Minh City, Ho Chi Minh City 70000, Vietnam; Email: nguyenthihonganh@iuh.edu.vn

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1. Introduction

Economic growth and environmental protection are two core factors in the sustainable development goals of any country. However, balancing economic benefits with ecological responsibility remains a challenge, especially as climate change becomes an increasingly urgent global issue. CO_2 emissions, one of the primary causes of the greenhouse effect, have posed serious challenges to the global economy. Notably, over the past 50 years, air pollution has shifted from a local issue to a global concern [1], compelling nations to find solutions to control emissions without hindering economic growth.

The agricultural sector plays a crucial role in the economic structure of many countries, as it is not only a key pillar of the economy but also a significant source of greenhouse gas emissions. Agricultural activities such as fertilizer use, livestock farming, and land-use changes contribute to increased CO_2 emissions. However, the relationship between agriculture, CO_2 emissions, and economic growth remains unclear in academic research. Some perspectives argue that economic development can help reduce emissions through the adoption of modern technologies and stricter environmental policies. Conversely, other studies suggest that without appropriate policy interventions, CO_2 emissions may continue to rise alongside economic expansion, including in the agricultural sector.

The Environmental Kuznets Curve (EKC) theory is a widely used hypothesis to explain the relationship between economic development and CO_2 emissions. According to the EKC, emissions tend to increase in the early stages of economic growth due to industrialization and agricultural expansion. However, once the economy reaches a certain level of development, stricter environmental regulations and technological advancements may help mitigate pollution [2]. Nevertheless, empirical studies indicate that this relationship does not always hold true, especially given that coal, oil, and natural gas consumption still play a dominant role in the energy structure of many countries [3]. This raises the question of whether nations can strike a balance between economic growth, agricultural development, and CO_2 emission control. Beyond its significant environmental impact, agriculture is also closely linked to economic growth. Agricultural exports are considered a driver of production, job creation, and national income growth, particularly in low-income countries. According to El Weriemmi and Bakari [4], agricultural exports positively influence economic growth in 12 low-income countries (Burkina Faso, Burundi, the Central African Republic, Ethiopia, Gambia, Madagascar, Mali, Niger, Rwanda, Sudan, Togo, and Uganda), highlighting the importance of agriculture in economic development. However, increasing agricultural production to meet export demand may also pose challenges in terms of resource use and environmental sustainability. Agricultural expansion can significantly increase greenhouse gas emissions due to land-use changes and resource-intensive farming practices. In their study *Assessing the Efficiency of Changes in Land Use for Mitigating Climate Change*, Searchinger and Wirsenius [5] found that land-use changes play a crucial role in climate policies, as the loss of natural vegetation and carbon-storing lands to make way for agriculture can account for up to 20–25% of global greenhouse gas emissions.

Given this context, as developed economies, these countries not only bear significant responsibility for controlling greenhouse gas emissions but also have the capacity to adopt advanced technologies to promote sustainable development. Therefore, this study focuses on the member countries of the Organisation for Economic Co-operation and Development (OECD), as they represent a group of highly developed economies with considerable differences in environmental policies and agricultural development strategies. OECD countries are not only at the forefront of driving economic growth but also pioneers in implementing CO_2 emission reduction policies. However, the impact of agricultural development and CO_2 emissions on economic growth in this group of countries remains insufficiently explored. Choosing OECD countries as the subject of this study provides a more comprehensive perspective on how nations at different levels of development address the challenge of balancing economic growth, agricultural expansion, and environmental protection.

The rest of this paper is structured as follows: Section 2 provides a brief overview of the relevant previous researches, Section 3 describes data, its source, model specification, and methodology which are used to regress results and empirical findings discussed in Section 4. Finally, in Section 5 we conclude the paper from empirical findings and policy implications derived from the findings.

2. Literature Review

The relationship between CO_2 emissions, agriculture, and economic growth is a topic that has garnered widespread interest in environmental economics research. This is because it not only reflects the challenges of balancing economic development and environmental protection but also underscores the urgent need for countries to formulate sustainable policies that control emissions while ensuring stable economic growth—especially in the context of climate change and global pressure to reduce emissions.

Several scholars have approached this issue through the Environmental Kuznets Curve (EKC) hypothesis, which suggests that as an economy develops, CO_2 emissions initially increase with rising income but later decline as technological advancements and environmental policies are implemented [2]. In the study "The Influence of Coal and Noncarbohydrate Energy Consumption on CO_2 Emissions: Revisiting the Environmental Kuznets Curve Hypothesis for Turkey," Pata [3] found that the Turkish economy follows the EKC pattern, with CO_2 emissions rising in the early stages and gradually decreasing as per capita income increases.However, many other studies emphasize that the EKC does not always hold, particularly for economies heavily reliant on heavy industry and fossil fuel energy [6]. In their study "Environmental Kuznets Curve & Effectiveness of International Policies," Satici and Cakir [7] analyzed data from 24 countries over 56 years and concluded that the EKC holds for high-income countries, where a clear downward trend in carbon emissions is observed once income reaches a certain threshold. Conversely, for countries that have not yet reached high-income status, the analysis suggests that it is premature to determine the validity of the EKC, as their per capita income has not yet reached the necessary level for evaluation.

However, some recent empirical studies challenge the traditional EKC framework. Dogan and Seker [8] investigated the relationship between CO_2 emissions, energy consumption, and economic growth in European countries and found that energy consumption is a primary driver of emissions, and economic growth alone is insufficient to reduce carbon intensity. Similarly, Balsalobre-Lorente and Shahbaz [9] provided evidence for an N-shaped relationship between economic growth and CO_2 emissions in EU-5 countries, indicating that emissions may rise again after an initial decline due to continued industrial expansion. These findings suggest that EKC dynamics vary across countries and time periods, necessitating region-specific environmental policies.

Moreover, agriculture plays a crucial role in the economy, especially in developing countries, where it remains a key driver of growth. Tiffin and Irz [10] analyzed the role of agriculture in economic growth and found that its development can contribute to national income enhancement in developing nations. In fact, agriculture can serve as a springboard for the development of industrial and service sectors [11]. However, agriculture is also one of the main sources of CO_2 emissions due to the use of chemical fertilizers, energy consumption, and land-use changes. Studies indicate that the expansion of cultivated land can lead to deforestation and increased greenhouse gas emissions [12].

Additionally, reality shows that the impact of agriculture on CO_2 emissions is influenced by the intensity of energy consumption in agricultural activities. For instance, the use of traditional fuels in agricultural machinery and the production of chemical fertilizers contribute significantly to greenhouse gas emissions. Implementing energy-efficient technologies and sustainable farming practices can help mitigate these emissions.

Today, the rapid advancement of modern technology has had a positive impact on all sectors of the economy. Zuo et al. [13] examined the impact of the digital economy on carbon emissions in 80 countries from 2010 to 2020. Their study found that digitalization can enhance production efficiency and reduce negative environmental impacts. Therefore, the development of smart agriculture, incorporating digital technology and renewable energy, could be a key strategy for optimizing sustainable economic growth. Additionally, the study by Bekhet and Othman [14] also emphasized that increasing the use of renewable energy can help control CO_2 emissions without slowing economic growth. One of the critical factors influencing CO_2 emissions is energy consumption, particularly from fossil fuel sources. Previous studies have shown that expanding the use of renewable energy plays a pivotal role in controlling emissions without compromising economic growth. For OECD countries, which have a high level of industrialization, the implementation of green energy policies is a prerequisite for reducing emissions without negatively affecting economic growth [8, 15].

Trade openness also influences CO_2 emissions and economic growth. Several studies suggest that increased trade liberalization can lead to higher emissions in the short term due to industrial expansion but may contribute to lower emissions in the long run by facilitating technology transfer. Using data from OECD countries, Copeland and Taylor [15] found that stringent environmental policies combined with trade openness could promote sustainable economic development. This highlights the need for coordinated environmental and trade policies to ensure long-term economic and ecological sustainability.

Existing researches indicates that the relationship between economic growth, CO_2 emissions, and agriculture is highly complex and depends on the characteristics of each country. The integration of digital technology into agriculture, the transition to clean energy, and the implementation of effective environmental management policies are crucial factors in achieving sustainable economic growth. Therefore, the objective of our study is to examine the impact of agriculture and CO_2 emissions on economic growth, especially in the OECD member countries, mostly developed countries where agriculture mainly uses modern technology to simultaneously evaluate CO_2 emissions from modern technology. From the results of previous empirical studies, it is shown that agriculture and CO_2 emissions both have a positive impact on economic growth, so we hypothesize that this impact is also positive in OECD member countries and the level is even stronger in the long term.

3. Data, Sources, Model Specification, and Methodology

3.1. Data

Agriculture plays a crucial role in the economies of developed countries. However, the impact of this sector, along with CO_2 emissions from other sources, on economic growth remains a critical issue that requires thorough examination. In this study, the author utilizes secondary data from 38 OECD member countries during the period 2000–2023 to analyze the relationship between agriculture, CO_2 emissions, and economic growth. The research variables include Agriculture (AGR), urban population growth (URB), CO_2 emissions, and economic growth (GDP), along with control variables such as per capita energy consumption (EC) and trade openness (TRADE). These variables are specifically defined in the following table (**Table 1**).

Table 1. Description of Research Variables.

Variables	Meaning	Data Sources
GDP	Annual GDP Growth Rate (% Growth)	WDI
CO_2	Average CO_2 Emissions, excluding emissions from LULUCF (Land Use Change and Forestry) (CO_2 emissions per capita)	WDI
AGR	Agriculture, Forestry, and Fishing, corresponding to ISIC sectors 1–3 (International Standard Industrial Classification) (% of GDP)	WDI
TRADE	Trade openness is the total of exported and imported goods and services (% of GDP).	WDI
EC	Per Capita Energy Consumption (kWh per person)	WDI
URB	Urban Population Growth Rate (annual %)	WDI

These variables play a crucial role in assessing the impact of CO_2 emissions and agriculture on economic growth in OECD member countries. Previous studies have demonstrated that agriculture positively influences economic growth [4, 16, 17]. However, the relationship between CO_2 emissions, agriculture, and economic growth has not been thoroughly explored, particularly when considering the role of trade openness and urban population growth. Therefore, this study aims to simultaneously evaluate the impact of these factors in OECD countries during the period 2000–2023.

3.2. Model Specification

The study delves into the simultaneous impact of CO_2 emissions, agriculture, and urban population growth (URB) on economic growth (GDP), with trade openness (TRADE) and energy consumption (EC) included as control variables in the model. The model employed in this study to assess these effects is the following linear regression model:

$$GDP_{i,t} = \alpha_0 + \alpha_1 * GDP_{i,t-1} + \alpha_2 * CO_{2i,t} + \alpha_3 * AGR_{i,t} + \alpha_4 * URB_{i,t} + \alpha_5 * X_{i,t} + \delta_i + \mu_t + \varepsilon_{i,t} \quad (1)$$

However, the data used to determine the impact of the research variables is an unbalanced panel dataset from 38 OECD member countries. Moreover, the inclusion of the lagged economic growth variable as an independent variable introduces endogeneity, multicollinearity, and autocorrelation issues, which cannot be adequately addressed using other linear regression methods due to data limitations. Therefore, the author employs the SGMM (System Generalized Method of Moments) regression approach to assess the impact of agriculture, CO_2 emissions, and urban population growth on economic growth.

Figure 1 illustrates the differences in the levels of fluctuation among economic, environmental, and trade-related factors. While GDP and trade exhibit strong volatility due to the impact of global economic events, agricultural growth and urban population growth remain more stable. Meanwhile, CO_2 emissions show a relatively stable trend, while energy consumption fluctuates significantly. Specifically: The trend analysis of key economic and environmental indicators reveals varying degrees of volatility and stability across different factors. GDP (diamond-shaped markers) demonstrates considerable fluctuations, with significant declines in 2008–2009 and 2020, likely corresponding to the global financial crisis and the COVID-19 pandemic. However, sharp rebounds in 2010 and 2021 suggest periods of recovery following these downturns. In contrast, agricultural growth (square-shaped markers) remains relatively stable, fluctuating within a narrow range. Unlike GDP, the agricultural sector appears to be less sensitive to global economic crises, maintaining steady growth even during major downturns. Meanwhile, CO_2 emissions (triangle-shaped markers) exhibit moderate fluctuations but do not show a clear increasing or decreasing trend. This stability may reflect the combined effects of industrial activity and environmental policies aimed at reducing emissions. Similarly, urban population growth (X-shaped markers) follows a steady trajectory with minimal fluctuations, suggesting that urbanization continues at a consistent pace, largely unaffected by short-term economic disruptions. On the other hand, energy consumption (star-shaped markers) experiences noticeable fluctuations, particularly around the 2008–2009 crisis and the 2020–2021 period. These variations may indicate changes in industrial activity, energy demand, and shifts toward cleaner energy sources. Lastly, trade activity (circle-shaped markers) displays strong volatility, with sharp declines during economic crises (2008–2009, 2020) followed by rapid recoveries. This pattern highlights the trade sector's high sensitivity to global economic fluctuations, reflecting the interconnected nature of international markets.

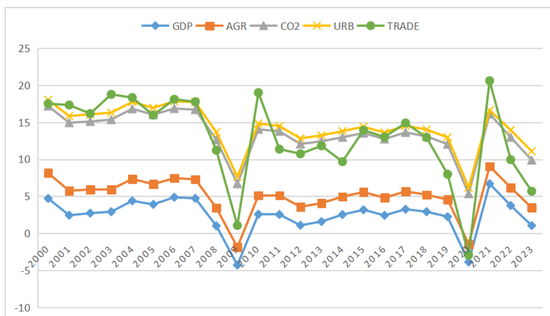


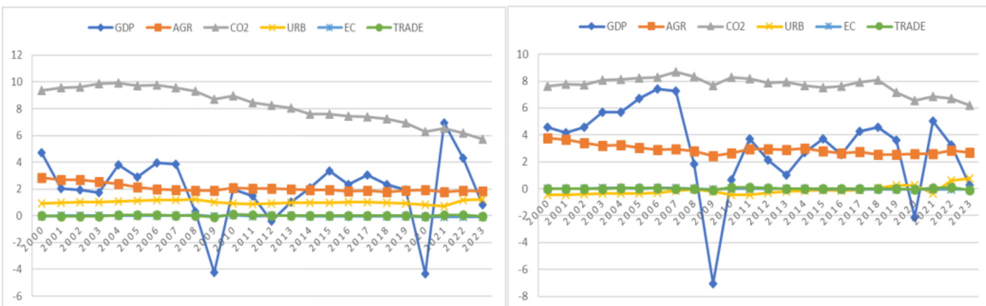
Figure 1. Trend Chart of the Average Variations in Economic Growth (GDP), Agriculture (AGR), CO_2Emissions, Urban Population Growth (URB), Energy Consumption (EC), and Total of Export and Import of Goods and Services (TRADE).

Source: Authors' calculation and drawing.

To gain an overview of the impact of agriculture, CO_2 emissions, urban population growth, and economic growth, we consider it essential to conduct a preliminary analysis of the average trends of these factors. This approach serves as a foundation for a clearer understanding of the subsequent empirical research findings. The average economic growth of OECD member countries fluctuated significantly during the period 2000–2023. Notably, the average GDP of these countries experienced sharp declines in 2009 due to the global economic crisis and in 2020 due to the impact of the COVID-19 pandemic. The agricultural sector in these countries remained stable with minimal fluctuations, indicating that economic growth in these nations does not heavily rely on agriculture. CO_2 emissions were effectively controlled and reduced from an average of 9.05 tons per capita to 6.42 tons per capita. Conversely, the average urban population growth in these countries remained stable and showed a significant upward trend in recent years, increasing from 0.488% in 2021 to 1.19% in later years. These factors appear to have little impact on CO_2 emissions, as their trends move in opposite directions—urban population growth has increased, while CO_2 emissions have declined.

When analyzing CO_2 emissions in more detail, both Western European countries (19 countries) and Eastern European countries (8 countries) showed a downward trend from 2000 to 2023 in **Figure 2.** However, Western European countries experienced a stronger reduction in CO_2emissions compared to Eastern European countries. Specifically, the average emissions in Western Europe decreased from 9.34 tons per capita to 5.74 tons per capita, while in Eastern Europe, they declined from 7.62 tons per capita to 6.22 tons per capita over the same period. This indicates that Western European countries have made more significant cuts in CO_2 emissions.

However, the contribution of agriculture to economic growth remains higher in Eastern European countries compared to Western European countries. Specifically, the agricultural sector in Eastern Europe maintained an average contribution of around 3.15% of GDP, while in Western Europe, it was 2.3% of GDP. This suggests that Eastern European countries still rely more on agricultural economies than their Western European counterparts.



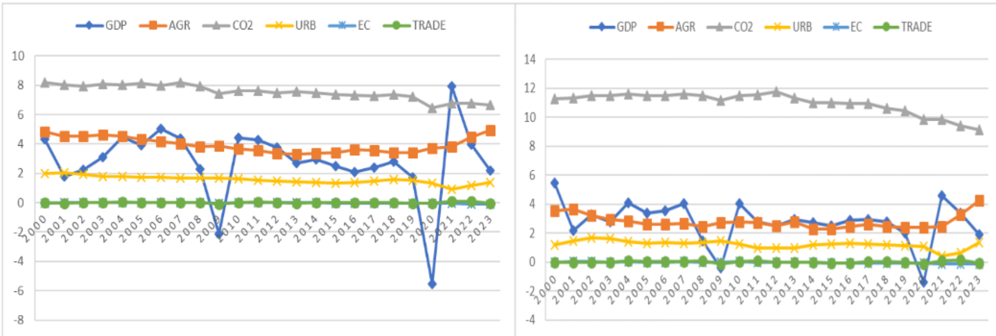
(a) Western Countries **(b) Eastern Countries**

Figure 2. Trend Chart of the Average Variations in GDP, AGR, CO_2, URB, EC, TRADE in Western Europe and Eastern Europe Countries in OECD.

Source: Authors' calculation and drawing.

For countries in the Americas and the Asia-Pacific region, the latter experienced a sharper reduction in average CO_2 emissions, dropping from a peak of 11.74 tons per capita to 9.16 tons per capita in **Figure 3**. In contrast, average CO_2 emissions in the Americas declined gradually in phases, from 8.18 tons per capita to 7.41 tons per capita in 2009, and further decreased to 6.45 tons per capita in 2020. This suggests that countries in the Americas are less dependent on CO_2-emitting industries compared to those in the Asia-Pacific region. Conversely, the Americas have shifted towards the agricultural sector, with its share of GDP rising gradually from 3.4% in 2019 to 4.93% in 2023, whereas in the Asia-Pacific region, the agricultural sector accounted for 2.45% of GDP in 2021 and increased to 4.26% in 2023.

The results indicate that most OECD member countries have reduced CO_2 emissions throughout the period from 2000 to 2023, with the contribution to economic growth primarily concentrated in countries in the Americas and the Asia-Oceania region.



(a) American Countries **(b) Asia-Oceania Countries**

Figure 3. Trend Chart of the Average Variations in GDP, AGR, CO_2, URB, EC, TRADE in America and Asia-Oceania Countries in OECD.

Source: Authors' calculation and drawing.

3.3. Methodology

First, we conduct preliminary tests to visualize data fluctuations and construct a correlation matrix to identify the relationships between independent and dependent variables, addressing potential multicollinearity issues in the models. Second, we test the stationarity of the variables using the Dickey-Fuller, Phillips-Perron, and Im-Pesaran-Shin tests. However, due to the unbalanced nature of the dataset and missing data for certain countries in specific years, potential serial correlation issues are not examined using test [18]. Furthermore, the panel data is dynamic, with lagged economic growth as an explanatory variable, which introduces endogeneity. These limitations can only be addressed using the System Generalized Method of Moments (S-GMM) [19]. Finally, the research team applies the one-step S-GMM method to verify the robustness of the empirical results and further enhance the study's understanding of the impact of green agriculture, CO_2 emissions, and urban population growth on economic growth in OECD member countries.

Using the Monte Carlo model approach, the system GMM estimator is more efficient than the two-step difference GMM estimator [20]. This is because the system GMM method combines both the differenced equation and the original equation as a Seemingly Unrelated Regression (SUR) system. In the first-order differenced equation, the instrumental variables used are the lagged values of the model's variables, with a minimum lag of one period. This simultaneous equation system is estimated using the GMM method.

The system GMM approach can control for individual-specific effects and potential endogeneity from independent variables. The efficiency of this GMM estimator is based on two hypothesis tests: the validity of the instrumental variables and the absence of correlation in the residuals. The presence of autocorrelation in the residuals is tested [19]. The appropriateness of the lagged variables used as instruments is tested using the Hansen test for overidentification restrictions.

Using the lagged values of independent variables as instruments in the system GMM method due to the following advantages: it controls for unobserved individual effects in the sample through the first-differenced equation and accounts for potential endogeneity from independent variables, including their lagged values [19]. The appropriate lags of independent variables are used as instruments. Therefore, we select the lagged values of independent and control variables as instruments, adjusting the lags sequentially until optimal conditions are met (Hansen test > 0.1 and AR test > 0.1), along with robust adjustments to ensure the model's robustness.

Figure 4 illustrates the research methodology process consisting of four main steps. First, a preliminary test is conducted using descriptive statistics and a correlation matrix to provide an overview of the data. Next, unit root tests (ADF, Phillips-Perron, Im-Pesaran-Shin) are applied to check stationarity and avoid spurious regression. Then, the model is estimated using the system GMM (S-GMM) method to address endogeneity issues. Finally, a robustness check is performed using the one-step system GMM to verify the stability of the research results.

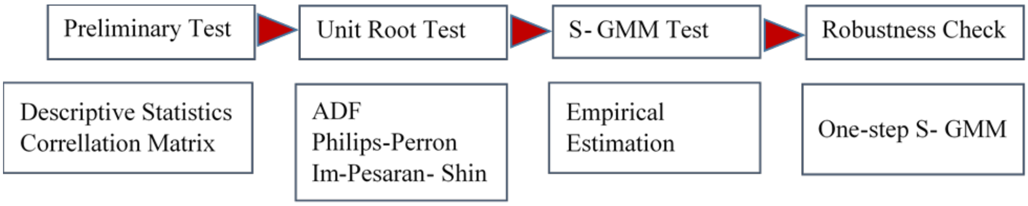


Figure 4. Flowchart of the Methodology.

3.4. Descriptive Statistics

Table 2 presents the descriptive statistics of the dataset in the research model. The descriptive statistics indicate that although most OECD member countries are high-income nations, the dispersion or variation of the studied variables is significant compared to their mean values. Additionally, the data does not follow a normal distribution, as evidenced by the Kurtosis and Jarque-Bera test results. The statistical results reveal considerable differences among OECD member countries. This is reflected in the GDP growth rate, which ranges from a maximum of 24.615% to a minimum of −16.040%. Similarly, per capita CO_2 emissions fluctuate between 3.593 tons and −5.828 tons per person, while green agricultural growth exhibits a notable variation, with the highest value at 10.190% and the lowest at 0.190%.

Table 2. Results of Statistics.

Variables	GDP	CO_2	AGR	TRADE	EC	URB
Mean	2.475	−0.114	2.612	0.857	66.271	0.885
Median	2.563	−0.061	2.034	1.037	42.466	0.875
Maximum	24.615	3.593	10.190	37.303	13211.41	4.065
Minimum	−16.040	−5.828	0.190	−77.694	−1511.823	−2.397
Standard Deviation	3.454	0.533	1.872	8.990	718.248	0.924
Skewness	−0.541	−1.151	1.489	−1.710	12.547	−0.086
Kurtosis	8.141	24.425	5.146	17.421	219.352	3.580
Jarque-Bera	1049	17000	507.3	8000	11000	13.91
Probability	0.000	0.000	0.000	0.000	0.000	0.00095
Observations	912	874	903	874	532	912

3.5. Correlation Matrix

When examining the correlation between variable pairs in the study, most pairs exhibit weak or very weak correlations, as classified by Evans [21], where a correlation coefficient below 0.4 is considered weak in **Table 3**. However, two variable pairs show stronger correlations compared to the others: CO_2 emissions have a positive correlation with GDP at 0.336, and energy consumption is positively correlated with CO_2emissions at 0.298. Based on these correlation results, we can conclude that the variables exhibit weak or very weak multicollinearity, which is further confirmed by the Variance Inflation Factor (VIF) test results presented in **Table 4**.

Specifically, the VIF analysis in table 4 indicates that the values are within an acceptable range, suggesting very weak or negligible multicollinearity, all below the threshold. Therefore, we can conclude that the variables in the research model do not exhibit multicollinearity, ensuring the reliability of the model.

Table 3. Correlation Matrix.

Variables	GDP	AGR	TRADE	CO_2	EC	URB
GDP	1.000	0.262	0.200	0.336	0.178	0.026
AGR	0.262	1.000	−0.054	0.150	0.141	0.181
TRADE	0.200	−0.054	1.000	0.183	0.136	−0.155
CO_2	0.336	0.150	0.183	1.000	0.298	−0.074
EC	0.178	0.141	0.136	0.298	1.000	0.035
URB	0.026	0.181	−0.155	−0.074	0.035	1.000

Table 4. Variance Inflation Factor (VIF).

Variables	VIF	1/VIF
CO_2	1.15	0.869
AGR	1.12	0.892
URB	1.07	0.937
TRADE	1.12	0.889
$GDP_{i,t-1}$	1.11	0.937

4. Results and Discussion

4.1. Stationarity Test

The stationarity test results of the variables in the model are presented in **Table 5**, conducted using the Augmented Dickey-Fuller (ADF), Phillips-Perron, and Im-Pesaran-Shin (IPS) methods. It can be observed that most variables are stationary according to the Augmented Dickey-Fuller (ADF) and Phillips-Perron tests.

Table 5. Stationary Test Result.

Variables	ADF		Phillips-Perron		IPS
	Inverse Logit	Modified Inv.	Inverse Logit	Modified inv.	Z(t-bar)
GDP	−12.319	16.905***	−17.377	25.464***	−10.800***
AGR	−4.732	5.498***	−7.452	9.608***	−5.550***
TRADE	−18.832	28.558***	−21.016	32.495***	−10.428***
CO_2	−22.081	34.135***	−34.501	56.272***	−14.829***
EC	−8.797	11.344***	−26.498	42.050***	−10.297***
URB	−2.540	0.0005***	−1.881	3.311***	−0.0095

Note: ***, **, * correspond to significance levels of 1%, 5%, and 10%, respectively.

4.2. Research Results

In this section, we will analyze the relationship between agriculture (AGR), CO_2 emissions (CO_2), and urban population growth (URB) with economic growth (GDP) in OECD member countries, while also examining the impact of these factors in both the short and long term. Specifically, we will apply appropriate econometric methods to assess whether agriculture has a positive or negative impact on GDP, whether an increase in CO_2 emissions hampers economic growth, and the role of urbanization in either driving or restraining the economy.

Table 6 presents the estimation results in two contexts:

Short-term: Examining the immediate effects of AGR, CO_2, and URB on GDP.

Long-term: Evaluating the sustainable impact of these factors on economic growth to provide a clearer understanding of long-term development trends in OECD countries.

The results from **Table 6** will offer essential empirical evidence, supporting policymakers in formulating sustainable development strategies that balance economic growth, environmental protection, and urbanization.

Table 6. Short Run and Long Run Results.

Variables	Short Run	Long Run
$GDP_{i,t-1}$	0.577*** (6.55)	1.367*** (2.77)
$AGR_{i,t}$	0.225*** (3.24)	0.532*** (3.13)
$TRADE_{i,t}$	0.269*** (3.03)	0.638** (1.94)
$CO_{2i,t}$	3.043*** (3.75)	7.205*** (2.95)
$EC_{i,t}$	−0.002*** (−3.29)	−0.006** (−2.52)
$URB_{i,t}$	0.217* (1.80)	0.514 (1.51)
Constant	0.163 (0.41)	
Observations	494	
Number of Countryid	38	
Sargan test of overid (Prob > Chi2)	13.25 0.066	
Hansen test of overid (Prob > Chi2)	10.93 (0.142)	
AR(2) (Pr > z)	−1.64 (0.101)	

Source: Authors' calculation.
*Note: *** p < 0.01, ** p < 0.05, * p < 0.1.*

The estimation results using the S-GMM method (**Table 6**) show that most variables are statistically significant at the 1% level, except for urban population growth (URB), which is significant at the 10% level. This suggests that the model specification is appropriate, and the selected variables provide meaningful insights into the factors influencing economic growth in OECD countries. Furthermore, the diagnostic tests, including the Sargan and Hansen tests, indicate that the instruments used in the estimation are valid, minimizing concerns about endogeneity. The absence of second-order autocorrelation, as confirmed by the AR (2) test, further strengthens the reliability of the results.

Regarding the impact of agriculture on economic growth, the results indicate that agriculture (AGR) positively affects economic growth. Specifically, in the short term, an increase in AGR leads to a 0.225% rise in GDP, and this impact continues to increase in the long term, reaching 0.532%. This suggests that agriculture plays a crucial role in driving the economies of OECD countries, aligning with previous studies [4, 16, 17, 22]. This finding highlights the significance of the agricultural sector, not only as a provider of food security but also as a key contributor to employment and rural development. The sustained long-term impact suggests that investing in modern agricultural techniques, improving supply chain efficiency, and ensuring access to financial services for farmers could further enhance agriculture's role in economic expansion. Additionally, technological advancements such as precision farming and climate-resilient crops can improve productivity, allowing agriculture to remain a stable pillar of growth despite environmental and market fluctuations.

Regarding the impact of CO_2 emissions, an interesting point is that CO_2 emissions (CO_2) stimulate economic growth. In the short term, the impact is 3.043%, and in the long term, it strengthens to 7.205%. This finding suggests that, at present, OECD countries may still rely on CO_2-emitting industries to drive growth. This result is consistent with previous studies, such as references [23–26]. The strong positive relationship between CO_2 emissions and economic growth indicates that carbon-intensive industries, such as manufacturing, transportation, and energy production, continue to be major drivers of GDP in these economies. While this reliance on fossil fuels and high-emission industries may boost economic output in the short term, it raises concerns about long-term sustainability. The potential costs associated with environmental degradation, regulatory penalties, and climate change mitigation policies could eventually offset these gains. Therefore, policymakers need to strike a balance between economic expansion and ecological responsibility by gradually transitioning to cleaner energy sources while maintaining industrial productivity.

Regarding the impact of urban population growth, the variable URB also shows a positive effect on economic growth in both the short and long term. Although its long-term impact is not as statistically significant as other variables, this result still suggests that urban expansion may contribute to GDP growth, in line with Pea-Assounga et al. [26], who examined the bidirectional relationship between urbanization and economic development. Urban areas serve as economic hubs, fostering innovation, business activity, and labor specialization. The concentration of economic resources in cities enhances productivity and efficiency, leading to higher GDP growth. However, rapid urbanization can also present challenges, such as infrastructure deficits, increased living costs, and socio-economic inequalities. To fully capitalize on the benefits of urban expansion, governments should invest in smart urban planning, transportation networks, and sustainable housing solutions. Integrating digital technologies into urban management can further improve the quality of life and economic productivity in growing cities.

The study also reveals that trade openness (TRADE) positively affects economic growth in both the short term (0.269%) and the long term (0.638%). This finding underscores the benefits of globalization, as increased trade facilitates market expansion, technological transfers, and access to diversified goods and services. Trade liberalization allows OECD countries to optimize their comparative advantages, strengthen industrial competitiveness, and attract foreign direct investment. Moreover, open trade policies contribute to economic resilience by reducing dependency on domestic demand and enabling participation in global supply chains. However, trade openness also exposes economies to external shocks, such as fluctuations in global demand, geopolitical tensions, and financial crises. To mitigate these risks, countries should implement policies that promote industrial diversification and enhance domestic production capabilities while maintaining strong international trade relations.

While energy consumption (EC) has a negative impact on economic growth, with a decline of –0.002% in the short term and –0.006% in the long term. This suggests that energy dependence may hinder long-term growth efficiency, similar to the findings of Mezghani and Haddad [27]. The negative association between energy consumption and GDP growth could stem from inefficiencies in energy use, high energy costs, or excessive reliance on non-renewable energy sources. In many OECD countries, energy-intensive industries face rising costs due to stricter environmental regulations and the push for carbon neutrality. Furthermore, energy inefficiency in production and distribution can act as a drag on economic performance, reducing competitiveness. Transitioning toward renewable energy sources and improving energy efficiency measures, such as smart grids and industrial automation, could help mitigate the adverse effects of energy consumption on economic growth. Additionally, investing in research and development (R&D) for cleaner energy technologies could provide long-term economic and environmental benefits.

Overall, the regression results provide critical evidence on the relationship between agriculture, CO_2 emissions, urbanization, trade, and energy consumption with economic growth in OECD countries. These findings emphasize the need for a balanced approach to economic development that integrates sustainability concerns while maintaining growth momentum. Agricultural development should be prioritized alongside technological innovation to ensure food security and rural economic stability. Likewise, transitioning away from CO_2-intensive industries requires well-structured policies that do not disrupt economic progress. Policymakers must also recognize the dual role of urbanization as both an economic catalyst and a potential source of socio-economic challenges, ensuring that cities remain engines of growth rather than centers of inequality.

These findings can help guide sustainable development policies, particularly in balancing economic growth with environmental considerations. Future research could explore sector-specific contributions to GDP growth, assess the impact of digital transformation on urban economies, and examine how OECD countries can transition to sustainable trade practices. Additionally, further analysis on the role of financial markets in supporting green energy investments could provide valuable insights for achieving a low-carbon economy without compromising economic performance.

4.3. Robustness Check

To verify the stability and reliability of the regression results in **Table 6**, the study conducts a robustness check by re-estimating the model using one-step SGMM instead of the previously used two-step SGMM. **Table 7** presents the robustness check results with the same dataset, covering 38 OECD countries from 2000 to 2023. The estimated coefficients maintain a consistent trend with the two-step SGMM model, thereby confirming the robustness and reliability of the empirical findings in this study.

Table 7. Short Run and Long Run Results (Robustness Check).

Variables	**Short Run**	**Long Run**
$GDP_{i,t-1}$	0.588*** (6.49)	0.143*** (2.67)
$AGR_{i,t}$	0.336*** (5.48)	0.817*** (3.87)
$TRADE_{i,t}$	0.305*** (3.68)	0.742** (2.45)
$CO_{2i,t}$	2.26*** (2.60)	5.497** (2.45)
$EC_{i,t}$	–0.0024*** (–4.38)	–0.006*** (–3.16)
$URB_{i,t}$	0.304** (2.15)	0.741 (1.64)
Constant	–0.163 (–0.4)	
Observations	494	
Number of Countryid	38	
Sargan test of overid (Prob > Chi2)	3.81 0.802	
Hansen test of overid (Prob > Chi2)	16.59 (0.020)	
AR(2) (Pr > z)	–1.46 (0.143)	

Source: Authors' calculation.
*Note: *** p < 0.01, ** p < 0.05, * p < 0.1.*

Overall, these results indicate that the research model is robust, further strengthening the reliability of the empirical findings regarding the impact of agriculture, CO_2 emissions, urbanization, trade, and energy consumption on economic growth in OECD countries. Specifically:

- Agriculture (AGR) continues to show a positive and statistically significant impact on economic growth in both the short term (0.336) and the long term (0.817), reinforcing the conclusion that agricultural development plays a crucial role in OECD economies.
- CO_2 emissions (CO_2) maintain a positive effect on economic growth, with a coefficient of 2.26 in the short term and 5.497 in the long term. Although the magnitude of the impact is slightly lower than in the two-step SGMM model, it remains highly statistically significant.
- Trade openness (TRADE) and urban population growth (URB) continue to positively influence GDP, with coefficients similar to previous results, confirming the role of trade integration and urbanization in economic growth.
- Energy consumption (EC) still has a negative impact on economic growth in both the short term (–0.0024) and the long term (–0.006), highlighting the importance of improving energy efficiency and transitioning to cleaner energy sources.

Additionally, the validity tests, including the Sargan test, Hansen test, and AR(2) test, confirm the high reliability of the model.

5. Conclusions and Policy Implications

The study analyzed the relationship between agriculture, CO_2 emissions, and urban population growth on economic growth in OECD member countries over more than two decades. Empirical results from the two-step SGMM model and robustness checks using the one-step SGMM approach indicate that agriculture has a positive impact on economic growth in both the short and long term while contributing to reducing energy consumption and CO_2 emissions. The findings further emphasize that sustainable agricultural practices can enhance productivity while mitigating environmental degradation. CO_2 emissions are positively correlated with economic growth; meanwhile, urban population growth has a positive effect on economic growth but also exerts pressure on infrastructure and the environment. Trade openness plays a crucial role in promoting growth, but regulatory policies are needed to ensure sustainability. In particular, the integration of green financing mechanisms can provide essential support for sustainable agricultural investments. Additionally, energy consumption negatively affects growth, highlighting the need to enhance energy efficiency and promote renewable energy.

Based on these findings, OECD countries should accelerate the adoption of advanced technologies in agriculture to enhance productivity and minimize environmental impacts. Supporting the development of smart agriculture models, utilizing waste recycling technologies to reduce CO_2 emissions, and encouraging investments in machinery powered by renewable energy instead of fossil fuels will enhance production efficiency and sustainable development. Furthermore, fostering international cooperation in sustainable agricultural research and technology transfer will be crucial for long-term economic and environmental resilience. Governments may implement carbon taxes and develop carbon credit markets to incentivize businesses to reduce emissions, as well as introduce policies supporting technological innovation in agriculture to optimize energy efficiency and reduce emissions.

Author Contributions

Conceptualization, A.H.T.N. and S.L.N.; methodology, S.L.N.; validation, S.L.N.; formal analysis, A.H.T.N. and S.L.N.; writing—original draft preparation, A.H.T.N.; writing— review and editing, A.H.T.N., S.L.N. and H.V.V. All authors have read and agreed to the published version of the manuscript.

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