




ASSESSING THE IMPACT OF AGRICULTURAL GROSS OUTPUT GROWTH ON GHG EMISSION INTENSITY: EVIDENCE FROM ANALYSIS OF STRUCTURAL FACTORS

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ABSTRACT

Aim of the study

This study assesses the intensity of greenhouse gas (GHG) emissions in agriculture, focusing on the effects of changes in both the dynamics and structural composition of agricultural gross output growth. The analysis aims to identify conditions under which a favorable balance can be achieved between socio-economic efficiency and environmental sustainability within the agricultural sector.

Materials and methods

Utilizing time-series linear regression models, the study investigates how variations in gross agricultural output, total factor productivity (TFP), and the relative contributions of the livestock and crop subsectors influence GHG emission intensity.

Results and conclusions

The empirical results indicate that accelerated growth in TFP consistently reduces emissions per unit of gross agricultural output, while its effect on emissions per hectare of agricultural land depends on structural growth factors. The findings further suggest that GHG emissions per hectare only decline when the share of TFP within the structure of growth sources substantially exceed a certain threshold. Conversely, changes in the share of the livestock sector in agricultural output growth influence both indicators of emission intensity in the same direction. Expanding scope of study on this issue led to a conclusion that the national-level assessments of agricultural GHG emission intensity should take into account the country's position in international trade in livestock products and the comparative GHG emission intensity levels of its main trading partners.

Keywords: greenhouse gas emissions, emission intensity, agricultural growth, TFP, structural changes

INTRODUCTION

Providing food for a steadily growing population depends on increasing overall agricultural production. This problem can be translated into ensuring the growth of production in national economies by meeting the growing domestic demand for agricultural

products and expanding participation in international trade. This should be accompanied with a realization of the potential export of products in which the country has a comparative advantage.

However, increasing agricultural production volumes also exacerbate the threat of global warming by contributing to higher greenhouse gas (GHG) emis-

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sions. Agriculture is rightly recognized as a source of considerable emissions, but at the same time there are opportunities for mitigation (Burney et al., 2010; Lynch et al., 2021). Furthermore, some studies indicate strongly that increasing carbon emissions can also have a negative impact on agricultural development through climate change (Mulatu et al., 2016, Khalilov et al., 2025).

Given that the expansion of the food system without reducing its environmental impact is considered to jeopardize global efforts to limit the rise in atmospheric temperature to 1.5°C above pre-industrial levels, there is a growing need to define the conditions for the effective reconciliation of food security and the reduction of the harmful effects of global climate change in the development of the agricultural sector. In this regard, we believe that special attention should be paid to the relationship between the growth of gross agricultural output and the dynamics of indicators characterizing the intensity of GHG emissions.

The factors that are directly responsible for GHG emissions in agricultural production, such as number of livestock, fertilizers use, and land cultivation, also shape the dynamics of gross output growth. The impact of these factors on the dynamics of gross agricultural output is expressed jointly and is also intertwined with the effects of other factors. Some of the latter factors can also have an indirect impact on GHG emissions.

In connection with the above, indicators characterizing gross output dynamics actually contain, in a “synthesized” form, the effects of factors that impact GHG emissions directly and indirectly. Based on this, we suggest studying the relationship between the structural factors determining growth dynamics and GHG emission intensity indicators to obtain more nuanced conclusions. Research on this issue is also important from the perspective of assessing the possibilities of ensuring food security in accordance with the principles of sustainable development, taking into account global aspects.

This paper is structured as follows. The current section presents the background and motivation of the study. The next section provides a review of the relevant literature. Section 3 outlines the research methodology, while Section 4 reports and discusses the empirical results. Finally, Section 5 concludes the paper by summarizing the main findings and their implications.

LITERATURE REVIEW

The link between agricultural expansion and GHG emission intensity has received growing attention in the sustainable development literature, as it reflects the trade-off between productivity growth and environmental protection. GHG emission intensity is usually measured as emissions per unit of agricultural output or per hectare of agricultural land (FAO, 2023). These indicators provide insight into technological performance and the production structure of the agricultural sector (Bai et al., 2024). Since 2010, empirical research on this topic has expanded rapidly (Burney et al., 2010; Bonesmo et al., 2012; Carol and Sands, 2013; Frank et al., 2018; Matthews, 2019; Bajan et al., 2022; Du et al., 2024; Godber and Wall, 2025). Available evidence shows that agricultural growth does not exert a uniform influence on emission intensity; outcomes vary with productivity dynamics, technological progress, and the composition of output (Frank et al., 2018).

A large body of work has been compiled on long-term developments in agricultural emissions. At the global level, emission rate per unit of output declined during periods of sustained intensification and production growth (Fuglie et al., 2024). However, point to a slowdown in this decline, and in some regions a partial reversal has been observed (Bai et al., 2024; Luo et al., 2024). At the same time, total agricultural emissions, including the emissions per hectare of land, have not fallen consistently across countries (OECD, 2023; OECD, 2025). Such divergent patterns are closely related to differences in developmental stages and sectoral configurations (Balogh, 2022; Sui and Lv, 2021; Zang et al., 2022).

In economies undergoing structural adjustment after periods of agricultural contraction, recovery phases are often accompanied by renewed growth in GHG emissions. This suggests that post-crisis expansion has rarely been guided by sustainability considerations. From a sustainability standpoint, agricultural growth should be guided not only by higher output but also by mitigated total emissions and declining emissions per unit of land and production. Determining the conditions under which these outputs can occur simultaneously remains therefore an important undetermined issue.

To address this issue, the present study applies two complementary measures of GHG emission intensity: emissions per hectare of agricultural land (EAGL) and emissions per unit of total agricultural output (EAGO). The first indicator captures land-related emission pressure and is widely used in empirical analyses (Lenerts et al., 2019; ABARES, 2025). The second expresses emissions relative to real agricultural output, in line with earlier approaches based on emissions per unit of monetary output (Mrówczyńska-Kamińska et al., 2021). These measures account for both land use effects and production efficiency, allowing for a more detailed evaluation of the environmental performance of agricultural growth.

The impact of total factor productivity (TFP) on GHG emissions has been examined extensively in analytical reviews and empirical studies. Evidence suggests that improvements in TFP generally contribute to a reduction in GHG emissions per unit of agricultural output, reflecting enhanced production efficiency (U.S. Environmental Protection Agency, 2025). However, despite declining emission intensity, several countries have experienced increases in total GHG emissions from agriculture (OECD, 2023). This indicates that the relationship between TFP growth and overall emission dynamics is not unidirectional.

One possible explanation is that higher productivity reduces production costs and stimulates output expansion, which in turn increases demand and the use of production inputs (Carol and Sands, 2013). In many cases, higher productivity is also associated with more intensive fertilizer application and other input use that substantially contributes to non-CO₂ emissions. Therefore, the environmental impact of TFP growth depends on whether output expansion is driven mainly by efficiency improvements or by greater resource use. The balance between these two forces plays a decisive role in shaping emission trajectories. Given the lack of consensus on the nature of the relationship between TFP and emissions, this study evaluates the effect of TFP within the context of its contribution to gross agricultural output growth.

Research has shown that shifts in productivity affect emission intensity indirectly by modifying the composition of agricultural output. Rising TFP has a significant impact on both the scale and composition

of output, particularly with regard to the relative importance of crop and livestock production (Valin et al., 2013). Structural change toward livestock production is especially pertinent due to its comparatively high emission intensity. While productivity improvements may cut emissions per unit of livestock, a larger livestock share in overall production can increase total emissions or slow their decrease (Valin et al., 2013). For this reason, assessments of structural change should consider not only domestic production patterns but also developments in international trade in livestock products, which may amplify or offset domestic emission effects.

DATA AND METHODOLOGY

Data

Main sources of data

The relevant data for Azerbaijan provided by the “Our World in Data” (2025) website (data from the national statistical agency for 2022) is used to calculate the annual volume of GHG emissions in agriculture. The volume of these indicators corresponds to the “Greenhouse Gas Emissions from Agriculture” data published by the Ministry of Ecology and Natural Resources (MENR) and the national statistical agency (State Statistical Committee of the Republic of Azerbaijan (SSC, 2025a)). When calculating the intensity indicators of GHG emissions, data on the area of agricultural land and the volume of gross output of agriculture at constant prices (in 2015 US dollars) were used. The data on Azerbaijan were published by the United States Department of Agriculture (USDA) Statistical Service in the country-specific data section of the relevant information portal (USDA, 2025).

The study is based on indices that express changes in relevant indicators. The volume index of total product production, as well as the indices of GHG emissions (in CO equivalent), are determined as a percentage of the ratio of the volumes of this indicator by year. In order to ensure the necessary comparability throughout the study, volume indices of total agricultural output, including crop and livestock products, as well as the annual indices of TFP in agriculture were also calculated based on the relevant data from the USDA Statistical Service.

The research period covered the years after the restoration of the state independence of the Republic of Azerbaijan, more specifically 1993–2022. The main information on the relevant indicators for that period is provided in the Appendix.

Dynamics of gross output of agriculture and the volume and intensity of GHG emissions

The dynamics of GHG emissions in agriculture displayed unique features in economies undergoing systemic transformation. This was due to the agrarian sector in these economies experiencing deep crises followed by periods of revival and development within a framework of a new system. As a transitioning economy, Azerbaijan’s agriculture saw significant decreases in the volume of gross output since the early 1990s, accompanied by a reduction in GHG emissions in this sector (Appendix). In 1991–1996, the physical volume of gross output of agriculture decreased by 1.8 times, and the volume of GHG emissions by 1.3 times (USDA, 2025; SSC, 2025a). In the subsequent period, as the growth in agricultural production resumed, GHG emissions also began to increase. During the period 1997–2015, as growth continued, the volume of production and GHG emissions increased by 2.6 and 1.7 times, respectively. The overall growth trend continued in the following period, in line with the dynamics of the physical volume of gross product, although there were some decreases in GHG emissions.

Although the long-term dynamics of GHG emissions in agriculture correspond to the global trend, the growth indicators for Azerbaijan have been relatively high. The average annual growth rate of GHG emis-

sions in 1997–2022 was 3.5%. The increase in GHG emissions in agriculture over time is consistent with the tendency of per capita CO₂ emissions in Azerbaijan to increase with economic growth, as found in another study (Suleymanov et al., 2025).

At the same time, the long-term growth dynamics of GHG emissions observed in this sector under Azerbaijan’s current level of agricultural development do not allow us to conclude that “economic development stimulates while agricultural development reduces CO₂ emissions”, as found in studies conducted on European countries (Balogh, 2022).

In the long term, there has been an increasing trend in EAGL and decreasing (Fig. 1).

At the same time, there were stage-specific features in the dynamics of the aforementioned indicators in that period. The EAGL decreased in 1993–1996, when production volumes were reduced, and then, as production revived, this indicator began to increase. After a medium-term decrease was observed since 2015, this tendency for increase was subsequently restored.

Changes in the dynamics of the EAGO indicator in Azerbaijani agriculture were observed in the opposite direction of the EAGL. The level of this indicator increased in 1993–1998, after in which came a period showing a general downward trend. Different correspondences are observed between the change in the volume of gross output and the change in the intensity of GHG emissions according to the indicators under consideration. This is also clearly evident in the graphical representations characterizing the dynamics of gross output and GHG emission intensity (Fig. 2).

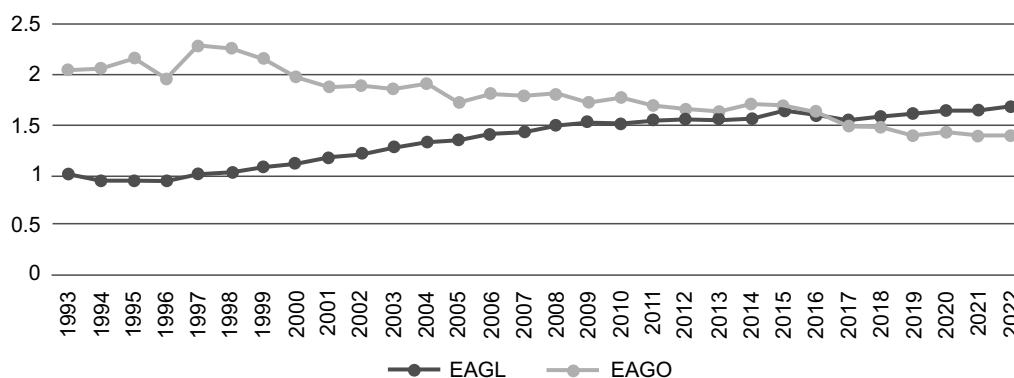


Fig. 1. Dynamics of GHG emission intensity indicators in Azerbaijan’s agriculture (Source: data from the Appendix)

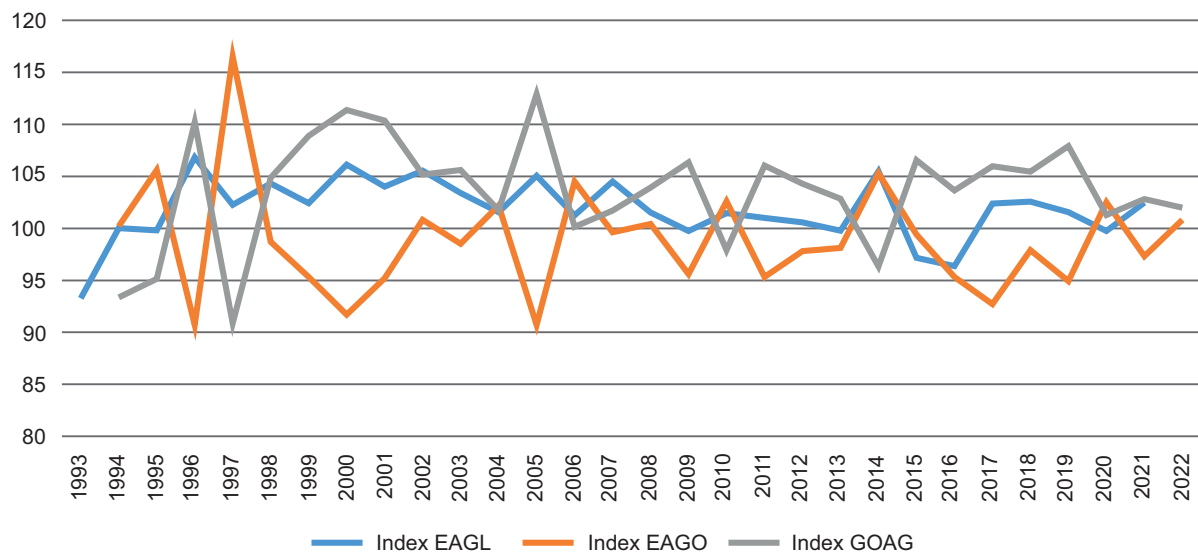


Fig. 2. Dynamics of gross product and GHG emission intensity indices in Azerbaijan’s agriculture in 1993–2022 (Source: data from the Appendix)

As can be seen in Figure 2, the directions of changes in the index of gross output of agriculture (IGOAG) and the index of GHG emissions per 1 ha of agricultural land (IEAGL) do not coincide in all cases. In some years, decreases in the physical volume of gross output of agriculture were accompanied by increases in the volume of emissions. At the same time, significant differences in the range of changes in the annual volume of emissions per 1 ha of agricultural land area were observed, despite the increase in total output. There is a general correspondence in the changes in the IGOAG and GHG indices per dollar of output (IEAGO), albeit in opposite directions. However, significant differences are observed in the range of changes in the corresponding indicator within the framework of the relationship under consideration. This, in turn, draws attention to the need to clarify the effects of changes in the structure of total agricultural production growth in the relevant direction during the period under study.

Methodology

Approach to qualitative analysis of the studied relationships

The relationship between the gross production volume and the indicators for volume and intensity of GHG emissions in agriculture is determined by the

changes in the number of livestock, the use of fertilizers and the area of cultivated land from production resources. The results of the “production-generation” function of the factors behind GHG can be extrapolated from the growth rates of gross output of agriculture. In this regard, the dynamics of the growth indicator will be tied to the changes in the GHG intensity indicators through the aforementioned factors. At the same time, when examining this relationship using time series data, it is necessary to take into account the impact of improvements in the productivity of the relevant resources.

The volume of production per 1 ha of agricultural land can be considered as an indicator of total productivity. However, it is affected by other factors besides the factors that are the direct source of GHG emissions. At the same time, taking into account the very general nature of this indicator, its relevance to our study is weak. In this regard, the use of the TFP indicator is considered more convenient.

Given that the effects of relevant factors on production volume and resource costs are reflected in TFP, it is acceptable to assume the idea that the dynamics of this indicator affect changes in the EAGL indicator. Nonetheless, it is necessary to note that this effect is indirect – occurring through changes in the consumption of GHG generating resources.

We examine the relationship of GHG intensity indicators with gross product growth and TFP in terms of the internal dependence of these two factors. In other words, TFP is considered one of the elements that constitute the structure of growth. Changes in the ratio of indicators characterizing the dynamics of gross product growth and TFP ultimately determine the direction and scale of progress in the share of TFP in the structure of growth. In this regard, the relationship between the changes in the share of TFP in the structure of growth and the intensity of GHG emissions can also be viewed as a joint expression of the relationship between GHG intensity and changes in these indicators.

Determination (selection) of indicators

In our study, the impact of changes in the volume of total agricultural production on the dynamics of GHG emissions is examined based on indices expressing their changes over the years. The impact of structural changes in total agricultural production is addressed in two directions. In the first direction, we analyze the impact of changes in the structure of gross output of agriculture, specifically the change in the share of the TFP factor in growth, In the second direction, we identify the impact of changes in the share of the livestock and crop sectors in agricultural production growth on the changes in the EAGL and EAGO indicators. We

also assess the changes in the share of TFP, the livestock sector, and the crop sector in the growth of gross output of agriculture based on the changes in the ratio of the indices expressing these to the volume index of gross output of agriculture. For instance, we take into account that the ratio of the volume index of livestock products to the volume index of gross output of agriculture represents the index of change in the specific weight of that sector’s products in output.

In the course of the study, the stationarity of the relevant variables in the series is initially checked. Analyses and relevant evaluations are carried out using the OLS method on the regression models of dynamic series consisting of stationary variables.

Tests of stationarity of time series

The stationarity of the time series variables of the data included in the study was conducted using the Stata program based on the augmented Dickey-Fuller (ADF) criterion. The results of the tests are given in Table 1.

As the table shows clearly, the variables related to crop-planted areas, perennial planting areas, pasture and mowing areas, agricultural investment, and the number of livestock are stationary, whereas the order of the index of change in livestock numbers is non-stationary.

Table 1. Results of the augmented Dickey-Fuller (ADF) test for stationarity of variables (Source: authors’ calculations using the STATA 15 program, based on application data)

Variables	Results of the test		Status
	Test statistical value	1% Critical value	
IEAGL	-5.259	-3.730	<i>Stationary</i>
IEAGO	-6.975	-3.730	<i>Stationary</i>
IGOAG	-5.800	-3.730	<i>Stationary</i>
ITFP	-4.513	-3.730	<i>Stationary</i>
ILP	-5.675	-3.730	<i>Stationary</i>
ICP	-5.460	-3.730	<i>Stationary</i>
ITFPSH (ITFP/IGOAG)	-4.355	-3.730	<i>Stationary</i>
ILSH (ILP/IGOAG)	-5.375	-3.730	<i>Stationary</i>
ICSH (ICP/IGOAG)	-5.430	-3.730	<i>Stationary</i>

Taking into account the above, the variable of livestock is included in the model in conditional units.

Inclusion of independent variables in the model

First, in the course of the study, the impact of changes in the volume of gross agricultural output on the considered GHG intensity indicator is examined separately based on regression analysis. Next, indicators reflecting structural changes in growth are included in the models. In this case, models are constructed in which indicators reflecting changes in the specific weight of the livestock and crop sectors in the growth of gross output are included separately, taking into account the multicollinearity factor.

$$IEAGL = a_0 + a_1 IGOAG + e_1 \quad (1)$$

$$IEAGO = a_2 + a_3 IGOAG + e_2 \quad (2)$$

$$IEAGL = b_0 + b_1 + b_1 \dot{I}GOAG + b_2 ITFPSH + b_3 ILSH + e_3 \quad (3)$$

$$IEAGO = \beta_4 + \beta_5 IGOAG + \beta_6 ITFPSH + \beta_7 ILSH + e_4 \quad (4)$$

$$IEAGL = \mu_0 + \mu_1 IGOAG + \mu_2 ITFPSH + \mu_3 ICSH + e_5 \quad (5)$$

$$IEAGO = \mu_4 + \mu_5 IGOAG + \mu_6 ITFPSH + \mu_7 \dot{I}CSH + e_6 \quad (6)$$

where:

- IEAGL – GHG emission index per 1 ha of agricultural land,
- IEAGO – GHG emission index per 1 USD of gross output of agriculture,
- IGOAG – index of gross output of agriculture,
- ITFPSH – index of TFP share in growth gross output of agriculture,
- ILSH – index of livestock sector share in growth gross output of agriculture,
- ICSH – index of crop sector share in growth gross output of agriculture,
- a_0, a_1 – regression coefficients for model (1),
- a_2, a_3 – regression coefficients for model (2),

b_0, b_1, b_2, b_3 – regression coefficients for model (3),

$\beta_4, \beta_5, \beta_6, \beta_7$ – regression coefficients for model (4),

$\mu_0, \mu_1, \mu_2, \mu_3$ – regression coefficients for model (5),

$\mu_4, \mu_5, \mu_6, \mu_7$ – regression coefficients for model (6),

$e_1, e_2, e_3, e_4, e_5, e_6$ – errors on the respective models.

Characteristics of descriptive data

The values obtained for the parameters of the models using data for the studied period are shown in the following table (Table 2).

All models, with the exception of model (1), are reliable according to the F-statistic criterion. In model (1), the regression coefficient of the independent variable – the volume index of the gross output of agriculture – did not receive a statistically significant value. The regression coefficient of the said independent variable is statistically significant at the 99% interval level in model (2). In model (3), the regression coefficient of the volume index of the gross output of agriculture from the independent variables is statistically significant at the 99% interval level, the regression coefficient of the index of the share of TFP in the growth of the gross output of agriculture, as well as the regression coefficient of the index of the share of the livestock sector in the growth of the gross output of agriculture are statistically significant at the 98% interval level. In model (4), the regression coefficient of the volume index of the gross output of agriculture and the regression coefficient of the index of the share of the livestock sector in the growth of the gross output of agriculture are statistically significant at the 99% level, and the regression coefficient of the index of the share of TFP in the growth of the gross output of agriculture are statistically significant at the 94% level.

The regression coefficient of the index of the share of the crop sector in the growth of the gross output of agriculture and the index of the share of the TFP in the growth of the gross output of agriculture, among the independent variables of model (5), is at the 98% limit interval, and the regression coefficient of the volume index of the gross output of agriculture is statistically significant at the 95% limit interval. The regression

coefficient of the volume index of the gross output of agriculture and the index of the share of the crop sector in the growth of the gross output of agriculture, among the independent variables of model (6), is statistically significant at the 99% limit interval, and the regression coefficient of the index of the share of the TFP in the growth of the gross output of agriculture is statistically significant at the 94% limit interval.

The values of the Durbin–Watson statistic for all models indicate that there is no autocorrelation in the residuals.

Table 2. Parameters of the model (Source: own calculation)

Indicators	Quantity	<i>t</i> -statistic	<i>p</i> -value
On model (1)			
R-multiple	0.2222		
F-statistic	1.40234		
Significance <i>F</i>	0.246659		
α_0	88.6761	7.998563	1.35E-08
α_1	0.126523	1.184189	0.246659
DW coefficient			
1.724903			
On model (2)			
R-multiple	0.868508		
F-statistic	82.89288		
Significance <i>F</i>	1.02E-09		
α_2	189.4109	19.01535	3.65E-17
α_3	-0.874	-9.10455	1.02E-09
DW coefficient			
1.645123*			
On model (3)			
R-multiple	0.6564		
F-statistic	6.30882		
Significance <i>F</i>	0.00246		
b_0	33.4885	0.94662	0.3529
b_1	0.47992	3.03496	0.00555
b_2	0.41653	2.45104	0.02158
b_3	-0.237	-2.4555	0.02137
DW coefficient			
2.16899*			

On model (4)			
R-multiple	0.92277		
F-statistic	47.7817		
Significance <i>F</i>	1.7E-10		
β_0	125.411	3.92677	0.0006
β_1	0.47561	3.33163	0.00269
β_2	-0.5556	-3.6213	0.0013
β_3	-0.1723	-1.9768	0.0592
DW coefficient			
2.02773			
On model (5)			
R-multiple	0.618654		
F-statistic	5.167022		
Significance <i>F</i>	0.006456		
μ_0	144.9855	7.727613	4.39E-08
μ_1	-0.24418	-2.43185	0.022522
μ_2	0.360187	2.053261	0.05065
μ_3	-0.5684	-2.55797	0.016972
DW coefficient			
2.224322			
On model (6)			
R-multiple	0.915904		
F-statistic	43.38821		
Significance <i>F</i>	4.65E-10		
μ_4	236.3207	13.94992	2.67E-13
μ_5	-0.17886	-1.97285	0.059668
μ_6	-0.60255	-3.80413	0.000818
μ_7	-0.5771	-2.87635	0.00811
DW coefficient			
2.104012			

RESULTUS AND DISCUSSIONS

The results of the regression analysis conducted separately between the volume IGOAG and the IEAGL according to the parameters of the model show that the changes in these indices trend in the same direction, but at the same time the indicator expressing the corresponding relationship does not meet the necessary reliability requirements. In this regard, it is impossible to confirm that the dynamics of the volume of gross output of agriculture acts as a factor actively influencing the change in the intensity of GHG emissions rel-

ative to the used land area in the absence of relevant structural changes.

However, when structural indicators of output growth are included in the model, the regression coefficient for the aforementioned indicator, as well as the regression coefficients of the indices of the shares of total output growth by TFP, and livestock and crop sectors acquire statistically reliable values. This reveals that these variables act as factors that have a real impact on the dynamics of GHG emissions per hectare of land area.

Thus, according to model (3), a 1 percentage point change in the volume index of gross output of agriculture causes a 0.49 percentage point change (increase or decrease) in the GHG intensity index in the corresponding direction. At the same time, a 1 percentage point change in the index characterizing the share of TFP in the growth of gross output causes a 0.24 percentage point change in the GHG intensity index by land area in the opposite direction, and a 1 percentage point change in the index characterizing the share of the livestock sector in the growth of gross output of agriculture causes a 0.42 percentage point change in the GHG intensity index by land area in the corresponding direction. According to model (4), a 1 percentage point change in the index characterizing the change in the share of the crop sector in the growth of the gross output of agriculture causes a 0.5 percentage point change in the corresponding GHG intensity indicator in the opposite direction. In other words, an increase in the share of the livestock sector in the growth of the gross output of agriculture leads to an acceleration of the growth of the intensity of GHG emissions per land area, while an increase in the share of the crop sector leads to a decrease. An increase in the share of TFP in the growth of the gross output leads to a weakening of the growth of the intensity of GHG emissions per land area. The effect of a change in the share of TFP on the index of emission intensity takes a smaller value in the linear combination of the indicator with the change in the share of the crop sector. In view of the above-mentioned, as well as the nature of the relationship between the intensity of GHG emissions per ha of used land and the dynamics of gross output of agriculture, it can be said that in a developing economy, where extensive resource expansion factors play a significant role, reducing GHG emissions conflicts with

accelerating growth in this sector. Eliminating this conflict requires changes in the structure of growth sources, primarily increasing the role of TFP. According to model (3), the effect of a 1 percentage point change in the volume index of gross agricultural product on a decrease in the GHG intensity index per ha of used land can be eliminated (“neutralized”) by a 2.2 percentage point increase in the index of the share of TFP in the growth of gross product.

At the same time, according to models (4) and (6), changes in the intensity indicator in question tend to move in the same direction as changes in the share of the livestock sector in the change in the growth indicator of gross output of agriculture, and in the opposite direction as changes in the share of the crop sector. A 1 percentage point increase in the value of the index expressing the share of the livestock sector in growth leads to an increase in the value of the index of the corresponding indicator of GHG intensity by 0.47 percentage points, while a 1 percentage point increase in the share index of the crop sector leads to a decrease in the value of that indicator by 0.58 percentage points.

The corresponding calculations based on the values of the regression coefficients of the models allow us to assess the impact of each factor on the dynamics of GHG intensity indicators during the period under study. In 1994–2022, the average annual value of the GHG emission index per 1 ha of agricultural land was 101.8%, and the average annual value of the GHG emission index per 1 USD of agricultural output was 98.8%. In other words, during the period in question, the value of the GHG emission index per unit of land area increased by an average of 1.8 percentage points per year, and decreased by an average of 1.2 percentage points per year compared to the value of the total output. Table 3 shows the values of the regression coefficients of the relevant models, reflecting the individual role (contribution) of the factors we included in the study in the formation of the mentioned dynamics of GHG emission intensity indicators.

The long-term rate of change in the volume of gross output of agriculture has led to an acceleration of the growth of GHG emissions in relation to the land area used. This process has been supported by changes in the structure of gross output growth. The general trends of a decrease in the share of TFP in growth in

Table 3. Assessment of the impact of GHG intensity factors by models (change in the average annual amount of the intensity indicator index due to the impact of the relevant factor – in percentage points) (Source: own calculations)

	IGOAG	ITFPSH	ILSH	ICSH
GHG emission index per 1 ha of agricultural land				
1994–2022	1.679726	0.6637	0.124958	0.05684
1994–2003	1.583742	0.568915	0.16661	0.17052
2004–2013	1.775711	1.066715	0.41653	0.397881
2014–2022	1.679726	0.355572	–0.29157	–0.34104
GHG emission index per 1 USD of gross of agriculture				
1994–2022	–1.94448	0.482375	0.1426831	0.05771
1994–2003	–1.83337	0.413464	0.1902441	0.17313
2004–2013	–2.0556	0.775246	0.4756103	0.4039701
2014–2022	–1.94448	0.258415	–0.332927	–0.34626

1994–2022, as well as an increase in the share of the livestock sector in the growth of gross output, played a significant role. The share of the mentioned structural factors accounted for approximately $\frac{1}{4}$ of the increase in GHG emissions per 1 ha of agricultural land. The trend of a decrease in the share of TFP in the growth of gross output covered the entire period under study. This factor also had an impact on the increase in the level of GHG emissions per 1 ha of agricultural land in individual decades. As a result of all this, the index characterizing the intensity of GHG emissions per 1 ha of agricultural land in 2014–2022 decreased significantly compared to previous periods.

The dynamics of the volume of gross agricultural output, in turn, influenced the decrease in the intensity of GHG emissions relative to the total output of 1 USD. At the same time, the course of this process was slowed down by the influence of changes in the index of the share of TFP in the growth of gross output. In 2014–2022, the dynamics of the indices of the share of the livestock and crop sectors in the change in the volume of gross output accelerated the rate of decrease in the intensity of GHG emissions relative to the total output produced.

Thus, the change in the share of the livestock sector in the growth of gross agricultural output moved in the same direction as the change in the intensity of GHG emissions, both in terms of 1 ha of land area used and in terms of 1 dollar of product production at comparable prices. This situation was closely related

to the characteristics of the processes taking place in the development of the livestock sector during the indicated period.

It should be noted that since 2016, the number of agricultural animals in the country has been steadily decreasing, and this trend continues. The number of beef cattle decreased by 80.4 thousand heads or 3.0% in 2016–2022. The respective decreases for sheep and goats amounted to 863 thousand heads and 10%. The decline in the number of agricultural animals has slowed the growth rate of livestock production. The average annual growth rate of livestock products in 2017–2022 was 1.5 percentage points lower than the corresponding indicator in 2011–2016. At the same time, GHG emissions were reduced in the corresponding direction. According to the results of calculations based on FAO data (2024), the total absolute volume of GHG emissions from livestock production in Azerbaijan decreased by 4.2%, from 6,385.1 thousand tons to 6,114.9 thousand tons of CO₂ equivalent in 2017–2022.

On the other hand, the decrease in the number of livestock and the related drop in the growth rate of livestock products have led to an increase in the purchase of live livestock from abroad and the import volumes of livestock products. This is significant information in the context of the country not achieving full self-sufficiency in the relevant products and increasing demand.

These products have had different GHG intensities in the countries where they are produced. The corre-

sponding differences in the emission levels for these products are consistently evident compared to the averages of the country’s main trading partners (Fig. 3).

As can be seen, the country’s GHG emission intensity is 1.8 times lower for beef, 1.2 times lower for mutton, and 1.7 times higher for cow’s milk compared to its main trading partners. This situation, in turn, has led to a situation where full self-sufficiency in the relevant products is not achieved, the GHG emission decreasing within the country is partially or completely offset by the GHG emission “imported into the country”. In this case, it matters how much the change in domestic emissions is “replaced” by imports of relevant products.

To clarify this issue, Figure 4 compares the potentially reduced volumes of meat and milk production due to the decrease in the number of productive animals with the potentially reduced volumes of GHG emissions based on the relevant intensity indicators by year.

As Figure 4 shows, the drop in the average annual volume of GHG emissions by 116 thousand tons, corresponding to the potential reduction in meat production due to the decrease in the number cattle, was offset by an increase in the average annual volume of GHG emissions by 168.2 thousand tons, corresponding to the increase in the import of the same volume of the product. The aforementioned indicators were 123.8 and 145.5 thousand tons for sheep meat, respectively.

The decrease in emissions for bovine milk was partially offset by a potential increase in the import of the corresponding product. At the same time, the potential amount of GHG reduced for all three considered products was 73.9 thousand tons of CO₂ equivalent or 1.3 times higher than the amount of emissions “entering the country” as a result of the potential increase in exports of the corresponding products. In other words, the potential amount of GHG reduced as a result of the decrease in the number of both large and small ruminant livestock was replaced by more GHG emissions due to the potential increase in imports of the corresponding products. In this case, the amount of the total difference was 2.3% in relation to the volume of GHG emissions generated in the country’s agricultural production of meat and milk in 2022. In other words, in this case, GHG emissions potentially increased, taking into account the changes in foreign trade in livestock products.

As can be seen, in both considered aspects, effective coordination of the tasks of ensuring food security and mitigating the negative effects of global climate change was not achieved. In this regard, the trend in the dynamics of the number of animals in the country in current conditions cannot be assessed as a favorable, either in terms of its impact on increasing food self-sufficiency, or in terms of mitigating the harmful effects of climate change, given the global scale of the issue.

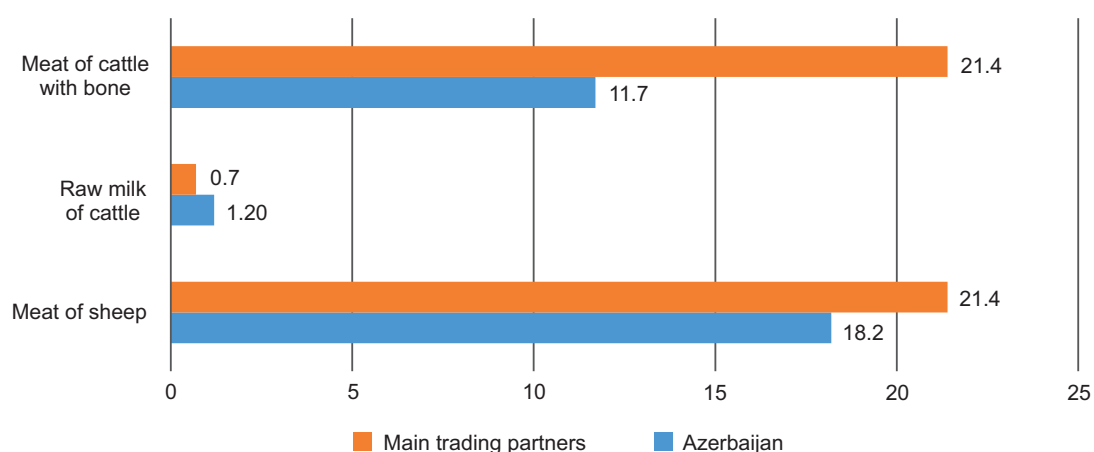


Fig. 3. Average annual GHG emission intensity for livestock products (kg/CO₂ eq) 2017–2022 (Source: own calculations based on FAO, 2024)

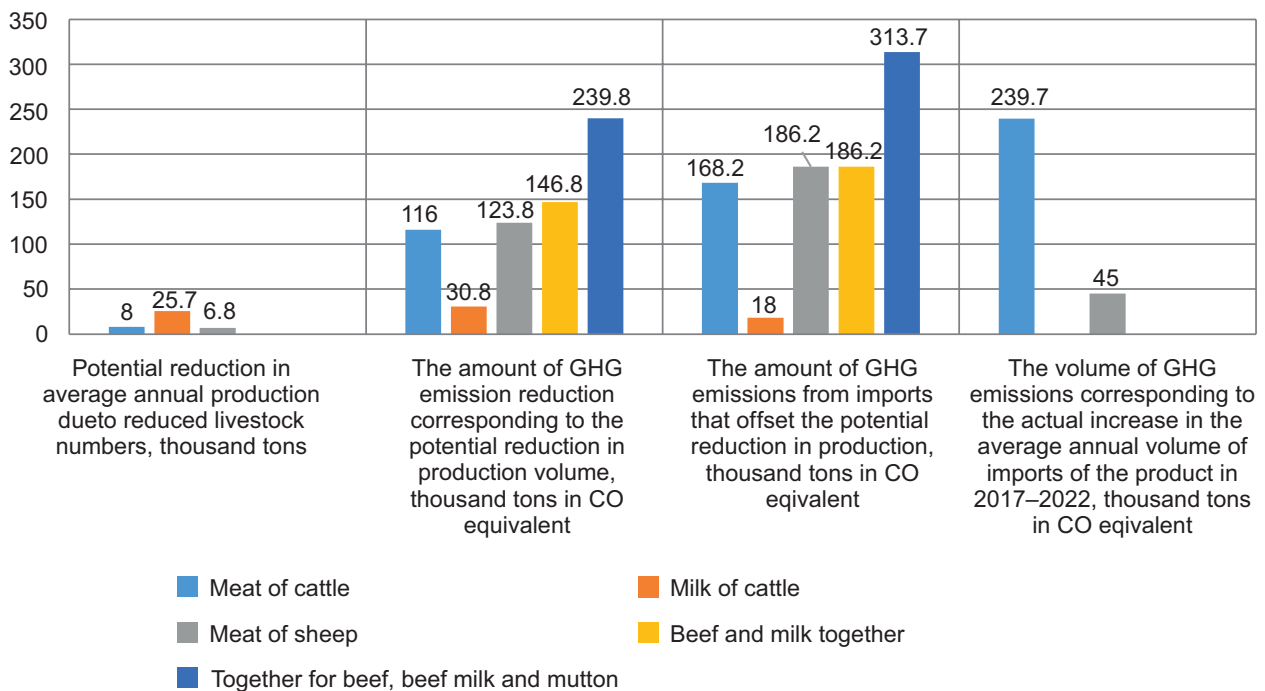


Fig. 4. Impact of livestock population decline on GHG emissions in 2017–2022 (Source: own calculations based on data from FAO, 2024; FAO, 2025; SSC, 2025a; SSC, 2025b)

CONCLUSION

To mitigate the adverse effects of global climate change, we must reconcile agricultural output growth with reductions in the greenhouse gas (GHG) footprint generated by the sector, as well as lowering the GHG intensity of agricultural products. Achieving this balance is essential for ensuring that agricultural development remains consistent with the principles of environmental sustainability.

The impact of agricultural output growth on GHG emissions depends not only on the rate of expansion but also on the structure of growth sources and the composition of production. The results of this study indicate that increases in the growth rate of agricultural production consistently influence emissions intensity per unit of output. However, reductions in emissions intensity per hectare of agricultural land occur only when the share of the productivity factor in the structure of growth sources rises substantially and surpasses a critical threshold. Under such conditions, agricultural growth becomes sustainable from the per-

spective of mitigating climate-related impacts. Thus, by shaping an appropriate structural configuration of growth sources, it is possible to achieve a coordinated resolution of socio-economic efficiency and environmental sustainability objectives in agricultural development.

At the same time, these processes may be interrupted, slowed, or accelerated by changes in the production structure, particularly by shifts in the share of livestock within total agricultural growth. Accordingly, it is necessary to assess the role of structural factors within a broader global framework, taking into account agricultural trade patterns and variations in product-level emission intensities across countries.

Empirical findings based on the case of Azerbaijan suggest that if a country is a net importer of livestock products and domestic production exhibits relatively low emission intensity, then expanding imports while reducing domestic livestock numbers could potentially increase total global GHG emissions. In a broader context, our findings prompt several considerations:

- Studies indicate that increased foreign trade in high-protein foods by net-importing countries with high domestic emission intensity may contribute to reductions in global emission intensity (Luo et al., 2024). However, the results of the present study demonstrate that this conclusion cannot be generalized to net-importing countries with relatively low emission intensity.
- While prior research (Balogh, 2022) correctly identifies the general global tendency for agricultural exports to exert upward pressure on GHG emissions in the rest of the world, our findings suggest that this effect may vary depending on country-specific conditions and product-level characteristics.

REFERENCES

- Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (2025). International farm emissions intensity statistics. <https://www.agriculture.gov.au/abares/research-topics/trade/climate/international-emissions-intensity-statistics>
- Bai, Z., Zhang, N., Winiwarter, W., Luo, J., Chang, J., Smith, P., Ledgard, S., Wu, Y., Hong, C., Conchedda, G., Ma, L. (2024). Decline in carbon emission intensity of global agriculture has stagnated recently. *Proc. Natl. Acad. Sci. U.S.A.*, 121(34), e2317725121. <https://doi.org/10.1073/pnas.2317725121>
- Bajan, B., Czyżewski, B., Matuszczak, A. (2022). Emission intensities of the food production system in the EU countries. *Journal of Cleaner Production*, 361, 132196. <https://doi.org/10.1016/j.jclepro.2022.132196>
- Balogh, J. (2022). The impacts of agricultural development and trade on CO₂ emissions? Evidence from the Non-European Union countries, *Environmental Science & Policy*, 137, 99–108. <https://doi.org/10.1016/j.envsci.2022.08.012>
- Bonesmo, H., Skjelvåg, A.O., Janzen, H., Klakegg, O., Tveito, O. (2012). Greenhouse gas emission intensities and economic efficiency in crop production: A systems analysis of 95 farms. *Agricultural Systems*, 110, 142–151. <https://doi.org/10.1016/j.agsy.2012.04.001>
- Burney, J., Davis, S., Lobell, D. (2010). Greenhouse gas mitigation by agricultural intensification. *Proc. Natl. Acad. Sci. U.S.A.*, 107 (26), 12052–12057. <https://doi.org/10.1073/pnas.0914216107>
- Carol, A., Sands, R.D. (2013). Impact of Agricultural Productivity Gains on Greenhouse Gas Emissions: A Global Analysis. *American Journal of Agricultural Economics*, 95(5), 1309–1316. <https://doi.org/10.1093/ajae/aat035>
- Du, R., Wang, J., Zhang, Y. (2024). Carbon emission changes of animal husbandry in China: Decomposition and spatial analysis. *Science of the Total Environment*, 913, 169632. <https://doi.org/10.1016/j.scitotenv.2024.169632>
- FAO (2023). OECD-FAO Agricultural Outlook 2023–2032 maps key output, consumption and trade trends. Rome. FAO. <https://www.fao.org/north-america/news/details/OECD-FAO-Agricultural-Outlook-2023-32-maps-key-output-consumption-and-trade-trends/en>
- FAO (2024). Greenhouse gas emissions from agrifood systems – Global, regional and country trends, 2000–2022. FAOSTAT Analytical Brief Series, 94. Rome. <https://openknowledge.fao.org/handle/20.500.14283/cd3167en>
- FAO (2025). Emissions intensities. Methodological note. FAOSTAT. https://files-faostat.fao.org/production/EI/EI_e.pdf
- Frank, S., Havlík, P., Soussana, J.F., Levesque, A., Valin, H., Wollenberg, E., Obersteiner, M. (2018). Structural change as a key component for agricultural non-CO₂ mitigation efforts. *Nature Communications*, 9(1), 1–10. <https://doi.org/10.1038/s41467-018-03489-1>
- Fuglie, K.O., Hertel, T.W., Lobell, D.B., Villoria, N.B. (2024). Agricultural Productivity and Climate Mitigation. *Annual Review of Resource Economics*, 16(1), 21–40. <https://doi.org/10.1146/annurev-resource-101323-094349>
- Godber, O., Wall, E. (2025). Farm-gate greenhouse gas emission intensity for medium-to-large dairy farms. *Journal of Dairy Science*, 108(2), 1112–1125. <https://doi.org/10.3168/jds.2024-18012>
- Khalilov, H., Fikratzade, F., Huseyn, R. (2025). The Influence of Average Annual Climatic Indicators on Agricultural Productivity: Considering the Threshold Effect *Agriculturae Conspectus Scientificus*, 90(1), 7–19. <https://acs.agr.hr/acs/index.php/acs/article/view/2575>
- Lenerts, A., Popluga D., Naglis-Liepa K. (2019). Benchmarking the GHG emissions intensities of crop and livestock-derived agricultural commodities produced in Latvia. *Agronomy Research*, 17(5), 1942–1952. <https://doi.org/10.15159/AR.19.148>
- Luo, J., Bai, Z., Zhang, N., Winiwarter, W., Chang, J., Smith, P., Chang, J., Ledgard, S. (2024). Global agriculture faces stagnation in reduction of greenhouse gas emission intensity. Bioeconomy Science Institute, AG Research Group. Conference contribution. <https://doi.org/10.57935/AGR.28004237.v1>
- Lynch, J., Cain, M., Frame, D., Pierrehumbert, R. (2021). Agriculture’s Contribution to Climate Change and Role in Mitigation Is Distinct From Predominantly Fossil CO₂-Emitting Sectors. *Frontiers in Sustaina-*

- ble Food Systems, 4, 518039. <https://doi.org/10.3389/fsufs.2020.518039>
- Mathews, A. (2019). Long-run perspective on EU agricultural output growth and GHG emissions. <https://capreform.eu/long-run-perspective-on-eu-agricultural-output-growth-and-ghg-emissions/>
- Mrówczyńska-Kamińska, A., Bajan, B., Pawłowski, K., Genstwa, N., Zmysłona, J. (2021). Greenhouse gas emissions intensity of food production systems and its determinants. *PLoS One*. 2021 Apr 30, 16(4). e0250995. <https://doi.org/10.1371/journal.pone.0250995>
- Mulatu, D., Eshete, Z., Gatiso, T. (2016). The Impact of CO₂ Emissions on Agricultural Productivity and Household Welfare in Ethiopia: A Computable General Equilibrium Analysis. *Environment for Development. Discussion Paper Series. Efd DP*, 16–08. <https://www.efdinitiative.org/sites/default/files/publications/efd-dp-16-08.pdf>
- OECD (2023). Integrated approaches for agricultural sustainability and productivity assessments (OECD Food, Agriculture and Fisheries Papers, No. 204). OECD Publishing. https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/09/integrated-approaches-for-agricultural-sustainability-and-productivity-assessments_6a791722/60cfa586-en.pdf
- OECD (2025). Network on Agricultural Total Factor Productivity and the Environment. Organisation for Economic Co-operation and Development. [https://www.oecd.org/en/networks/network-on-agricultural-total-factor-productivity-and-the-environment.html#:~:text=Total%20Factor%20Productivity%20\(TFP\)%20is,implies%20producing%20more%20with%20less](https://www.oecd.org/en/networks/network-on-agricultural-total-factor-productivity-and-the-environment.html#:~:text=Total%20Factor%20Productivity%20(TFP)%20is,implies%20producing%20more%20with%20less)
- Ritchie, H., Roser, M. (2025). Azerbaijan: CO₂ Country Profile. *Our World in Data*. <https://ourworldindata.org/co2/country/azerbaijan>
- Sui, J., Lv, W. (2021). Crop Production and Agricultural Carbon Emissions: Relationship Diagnosis and Decomposition Analysis. *International Journal of Environmental Research and Public Health*, 18(15), 8219. <https://doi.org/10.3390/ijerph18158219>
- Suleymanov, E., Kazimov, S., Safarli, E., Alirzayev, E. (2025). Carbon Emissions and Economic Growth in Azerbaijan: An Empirical Analysis. *International Journal of Energy Economics and Policy*, 15(5), 301–309. <https://doi.org/10.32479/ijeeep.20017>
- The State Statistical Committee of Azerbaijan Republic (SSC) (2025a). Environmental Protection. <https://www.stat.gov.az/source/environment/?lang=en>
- The State Statistical Committee of Azerbaijan Republic (SSC) (2025b). Agriculture, forestry and fishing. <https://www.stat.gov.az/source/agriculture/?lang=en>
- U.S. Environmental Protection Agency (2025). Agriculture sector emissions: Sources of agriculture sector emissions. <https://www.epa.gov/ghgemissions/agriculture-sector-emissions#sources>
- USDA (2025). International Agricultural Productivity-Documentation and Methods. Economic Research Service. U.S. Department of Agriculture. <https://www.ers.usda.gov/data-products/international-agricultural-productivity/documentation-and-methods>
- Valin, H., Havlik, P., Mosnier, A., Herrero, M., Schmid, E., Obersteiner, M. (2013). Agricultural productivity and greenhouse gas emissions: Trade-offs or synergies between mitigation and food security? *Environmental Research Letters*, 8(3), 1–9. <https://doi.org/10.1088/1748-9326/8/3/035019>
- Zang, D., Hu, Z., Yang, Y., He, S. (2022). Research on the Relationship between Agricultural Carbon Emission Intensity, Agricultural Economic Development and Agricultural Trade in China. *Sustainability*, 14(18), 11694. <https://doi.org/10.3390/su141811694>

Appendix. Data on indicators included in the study

Years	GHG emission volume, mln t CO ekvivalent*	GHG emission index per 1 ha of agricultural land ** (IEAGL)	GHG emission index per 1 USD of gross output of agriculture** (IEAGO)	Index per of gross output of agriculture *** (IGOAG)	Index of livestock products*** (ILP)	Crop production volume index*** (ICP)	Index of total factor productivity *** (ITFP)	Index of TFP share in growth gross output of agriculture*** (ITFP/IGOAG)	Index of livestock sector share in growth gross output of agriculture*** ILSH (ILP/IGOAG)	Index of crop sector share in growth gross output of agriculture,*** ICSH (ICP/IGOAG)
1993	4360	93.3	100.2	93.3	97.7	93.2	97.9	106.7	100.2	99.9
1994	4080	100.0	105.6	95.1	93.6	91.2	99.6	101.1	106.4	95.9
1995	4100	99.8	90.7	110.2	101.3	114.4	96.2	103.1	94.7	103.8
1996	4100	106.8	116.5	90.9	104.4	80.3	113.6	105.9	117.6	88.4
1997	4340	102.3	98.7	104.9	106.8	101.8	96.2	93.6	103.4	97.0
1998	4490	104.3	95.3	108.9	108.4	112.8	98.2	87.4	96.1	103.6
1999	4660	102.4	91.7	111.4	104.7	117.5	95.2	89.8	93.7	105.5
2000	4760	106.1	95.2	110.3	104.4	115.1	100.0	87.5	94.5	104.3
2001	5001	104.0	100.8	105.2	104.2	105.1	96.6	99.6	100.1	100.0
2002	5300	105.5	98.5	105.6	105.2	105.7	104.8	103.7	99.9	100.1
2003	5510	103.4	102.2	101.7	105.5	99.4	109.5	99.3	103.3	97.7
2004	5730	101.6	90.7	112.9	105.0	120.2	101.0	96.6	91.2	106.5
2005	5870	105.1	104.5	100.1	103.0	98.2	109.0	92.3	103.0	98.1
2006	6140	101.2	99.6	101.7	103.2	99.6	92.4	89.1	103.0	97.9
2007	6220	104.5	100.4	103.9	104.8	104.4	90.7	92.2	99.3	100.5
2008	6490	101.5	95.6	106.3	103.2	102.9	95.8	95.3	104.6	96.8
2009	6600	99.7	102.6	97.9	111.2	91.0	101.3	103.8	109.5	92.9
2010	6630	101.5	95.3	106.0	107.2	109.5	101.6	96.4	96.4	103.3
2011	6700	101.0	97.8	104.3	102.2	104.3	102.2	95.2	100.0	100.0
2012	6830	100.5	98.1	102.8	104.3	102.3	99.3	96.1	100.7	99.5
2013	6890	99.8	105.3	96.3	103.5	91.5	98.8	96.0	106.0	95.0
2014	6990	105.5	99.4	106.6	102.1	110.4	92.5	94.9	96.1	103.6
2015	7400	97.2	95.3	103.6	102.4	103.2	101.1	105.0	100.5	99.6
2016	7310	96.4	92.7	106.0	104.1	110.0	108.8	102.7	95.6	103.8
2017	7180	102.4	97.9	105.4	101.3	108.0	108.8	96.8	97.0	102.4
2018	7410	102.6	94.9	107.9	102.3	109.8	102.1	95.8	97.6	101.8
2019	7590	101.5	102.5	101.3	105.3	100.2	103.4	99.3	101.5	98.9
2020	7880	99.7	97.3	102.8	102.8	103.4	100.6	100.0	99.2	100.6
2021	7880	102.5	100.8	102.0	102.0	101.7	102.8	94.9	100.4	99.7
2022	8100	93.3	100.2	93.3	102.4	93.2	97.9	106.7	100.2	99.9

Sources:

* Ritchie and Roser, 2025; SSC, 2025a

** Author's calculations based on data from Ritchie and Roser (2025) and USDA (2025)

*** Author's calculations based on data from USDA (2025)

OCENA WPŁYWU WZROSTU GLOBALNEJ PRODUKCJI ROLNEJ NA INTENSYWNOŚĆ EMISJI GAZÓW CIEPLARNIANYCH: DOWODY Z ANALIZY CZYNNIKÓW STRUKTURALNYCH

ABSTRAKT

Cel badania

W niniejszym badaniu oceniono intensywność emisji gazów cieplarnianych w rolnictwie, skupiając się na skutkach zmian zarówno w dynamice, jak i strukturze wzrostu produkcji rolnej brutto. Analiza ma na celu ustalenie warunków, w których można osiągnąć optymalną równowagę między sprawnym funkcjonowaniem społeczno-gospodarczym a zrównoważonym rozwojem środowiskowym w sektorze rolnym.

Materiały i metody

Korzystając z modeli regresji liniowej szeregów czasowych, w badaniu analizie poddano wpływ zmian w produkcji rolnej brutto, całkowitej wydajności czynników produkcji (TFP) oraz względnego udziału podsektorów hodowli zwierząt i upraw na intensywność emisji gazów cieplarnianych.

Wyniki i wnioski

Wyniki badania wskazują, że przyspieszony wzrost TFP konsekwentnie obniża emisje na jednostkę produkcji rolnej brutto, podczas gdy jego wpływ na emisje na hektar gruntów rolnych zależy od strukturalnych czynników wzrostu. Wyniki sugerują ponadto, że emisje gazów cieplarnianych na hektar maleją tylko wtedy, gdy udział TFP w strukturze źródeł wzrostu znacznie przekracza pewien próg. Natomiast zmiany udziału sektora hodowlanego we wzroście produkcji rolnej wpływają na oba wskaźniki intensywności emisji zgodnie z tym samym trendem. Poszerzenie zakresu badań w tej kwestii pozwoliło na wyciągnięcie wniosku, że oceny intensywności emisji gazów cieplarnianych w rolnictwie na poziomie krajowym powinny uwzględniać pozycję danego kraju w międzynarodowym handlu produktami pochodzenia zwierzęcego, jak również porównawcze poziomy intensywności emisji gazów cieplarnianych u jego głównych partnerów handlowych.

Słowa kluczowe: emisje gazów cieplarnianych, intensywność emisji, wzrost produkcji rolnej, TFP, zmiany strukturalne