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ENVIRONMENTAL SUSTAINABILITY DETERMINANTS OF AGRICULTURAL PRODUCTIVITY IN THE BALTIC STATES

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Abstract
Agriculture faces growing sustainability challenges due to increasing environmental pressures and the need to ensure long-term food security. This article examines the impact of environmental sustainability indicators, such as ammonia and greenhouse gases, nitrogen and phosphorus fertilisers, water consumption, area under organic farming, energy consumption and waste generation, on agricultural productivity in the Baltic countries. The research methodology involved a comparative analysis and the calculation of Pearson's correlation coefficients, as well as the application of simple linear regression, using Eurostat data from 2012 to 2022. The results showed that productivity is most strongly influenced by greenhouse gases and nitrogen fertilisers in Estonia and Latvia and by the area under organic farming in Latvia and Lithuania. Meanwhile, energy consumption had a positive impact in Latvia and Lithuania, but a negative one in Estonia. These results are important for shaping environmental and agricultural policy in the Baltic region, aiming to balance productivity growth with sustainability goals.

Keywords: *sustainable agriculture, environmental indicators, agricultural productivity, Baltic States, econometric analysis, regression analysis.*

Introduction

In recent decades, sustainability has become a particularly important issue for businesses in various economic sectors due to environmental damage. Although sustainable development encompasses three aspects – environmental, social and governance – the environmental aspect usually receives the most attention. It is important to note that the agricultural sector contributes to global environmental change and faces its consequences (Biagetti et al., 2025). This means that, to ensure the long-term provision of food for the world's population, agriculture must be developed sustainably, particularly regarding environmental considerations.

Throughout most of human history, various technological innovations have been introduced to increase agricultural production with limited resources (Khan et al., 2021). Biotechnology is one such tool, helping to improve crop quality and increase potential yields (Das et al., 2023). Applying green economy principles to agriculture is also important, as balancing economic benefits and sustainability ensures the long-term prosperity of sustainable agriculture (Kausar et al., 2024). Authors such as Biagetti et al. (2025), German et al. (2017), Florea et al. (2021) and Mergoni et al. (2024) have already studied the issue of sustainable development and agricultural productivity. This article aims to examine the impact of sustainable development on agricultural productivity in the Baltic countries.

To assess the impact of environmental sustainability indicators on agricultural productivity in the Baltic States using correlation and regression analysis over the period 2012–2022.

This study is relevant because there is a need to understand how environmental factors influence the productivity potential of the agricultural sector in the various Baltic countries. The analysis provides a foundation for the development of more sustainable agricultural policies, based on the empirical links between sustainability indicators and economic performance.

Literature Review

Over the past decade, sustainable development has received significant attention, as industries and companies whose activities directly harm society and the environment have come under criticism (Darvishi et al., 2023). Soretz et al. (2023) and Mensah (2019) describe it as an approach that seeks to balance environmental, social

and economic issues while ensuring that current societal needs are met without causing additional harm to future generations.

The most pressing environmental issue is climate change, leading to rising temperatures, sea levels and glacier melt, as well as droughts, floods and other uncontrollable natural phenomena (Esmailnejad, 2024). Other issues, such as water and air pollution, greenhouse gases and the use of natural resources, are also highlighted.

As the world's population grows, so does the demand for food. Current crop yields are no longer sufficient, so it is crucial that the agricultural sector addresses the productivity crisis (Shah et al., 2021). While higher agricultural productivity can help to meet the growing global demand for food in the short term, to ensure a long-term food supply, farming must be sustainable (German et al., 2017). When applying sustainability principles to agriculture, two key aspects must be considered: environmental conservation and providing safe and healthy food to the public (Meena, 2023). Furthermore, developing sustainable and climate-resilient agriculture requires not only environmental protection, but also economic and social benefits (Das et al., 2023).

Agriculture is one of the leading sectors responsible for polluting surface and groundwater due to excessive agrochemical use, poor post-harvest waste management and traditional irrigation systems (Rey-Romero et al., 2022). The growing global demand for food is driving the increased use of pesticides in agriculture to reduce crop losses, ensure food quality, and maintain affordability (Tudi et al., 2021).

To address the challenge of ensuring long-term food security, it is crucial to adopt sustainable agricultural methods and practices (Muhie, 2022; Das et al., 2023). One approach that could contribute to sustainable agricultural development is organic farming. This method of farming is defined as an environmentally friendly agricultural system that avoids the use of synthetic chemicals and fertilisers (Kumar et al., 2023; Smith et al., 2019).

When comparing different farming methods, it has been observed that traditional farming causes significantly greater environmental damage, severely impacting critical agricultural resources such as soil and biodiversity. This makes growing conditions more

challenging for both organic and conventional farms, leading to soil erosion and degradation (Montgomery & Biklé, 2021). Furthermore, the chemicals used on conventional farms negatively impact not only the environment and ecosystems, but also human health (Yanakittkul & Aungvaravong, 2020; Sapbamrer & Thammachai, 2021).

The sustainable development of farms is most often assessed in terms of three aspects of sustainability. However, the authors Milestad et al. (2024), Nadaraja et al. (2021) and Huck et al. (2024) emphasise that agriculture primarily focuses on environmental protection. The authors Kausar et al. (2024), Milestad et al. (2024), Mitova (2021) and Nadaraja et al. (2021) assess the sustainability of agriculture using indicators such as water and energy consumption, fertiliser use and factors contributing to air and water pollution. When analysing social and economic factors, attention focuses on farm workers and working conditions, while the latter focuses on production output, profits earned and other factors. In assessing farm sustainability, the authors Alonso-Martinez et al. (2024) also sought to identify the factors driving sustainability initiatives. These can be internal factors directly related to the individual farm or external factors indirectly related but capable of affecting the farm.

Huck et al. (2024) emphasise in their study that agriculture negatively impacts the environment and is one of the main industries whose activities generate significant greenhouse gas emissions. Based on a review of existing studies, it can be concluded that the sustainable development of agriculture is a pressing issue. To assess the sector's sustainability, measurable sustainability indicators are employed to inform the progressive pursuit of sustainability initiatives and reduce the negative environmental impact of agriculture.

Correlation and regression analyses are the most commonly used methods for studying the relationship between sustainability and agricultural productivity. Biagetti et al. (2025) found in their study that extensive farming practices may be more sustainable and have a lower environmental impact than intensive farming practices. They also argue that innovative farming practices must be adopted to reconcile agricultural productivity with sustainability and reduce environmental damage, as this would increase food production while reducing the ecological damage caused by agriculture. However,

German et al. (2017) contend that quantifying agricultural sustainability is challenging due to the varying environmental impacts of different farming methods depending on the location of agricultural activity. This study found a strong positive correlation between changes in crop yield and changes in profit (German et al., 2017). Florea et al. (2021) examined the relationships between agricultural productivity and its influencing factors, including human, ecological, economic, social and technological factors. Finally, Mergoni et al. (2024) noted in their study that environmental risks affect the efficiency of the agricultural sector and place a greater burden on more vulnerable countries.

In summary, when assessing the sustainability of the agricultural sector, the greatest emphasis is placed on environmental protection. This is because agriculture contributes to environmental damage and faces its consequences. Addressing environmental issues is particularly important given the growing global population and the resulting increase in food demand. Therefore, ensuring long-term food security makes sustainability in agriculture especially significant.

Research Methodology

An empirical study of sustainability indicators for farms in the Baltic States was conducted to determine the impact of sustainable agricultural development trends on farm productivity. Eight such indicators, presented in Table 6.7, were analysed. These were selected following an analysis of studies by authors such as Milestad et al. (2024), Mitova (2021) and Nadaraja et al. (2021) (Table 6.7).

Secondary data from the Eurostat database was collected for the study. This data was analysed over a ten-year period, incorporating the most recent available data from 2012 to 2022. The value of production in euros for the 2012–2022 period was also analysed. This period was chosen to ensure data consistency and comparability across all three countries.

The empirical analysis is based on a comparative econometric framework. The dependent variable is the value of agricultural output (in EUR), while the independent variables include environmental sustainability indicators such as greenhouse gas emissions, fertiliser use, energy consumption and the area dedicated to organic farming.

Table 6.7

An analysis of sustainability indicators in the agricultural sector

The theme of sustainability	Indicator	Period	Conducted research	Database
Air pollution	Ammonia emissions	2012-2022	Mitova (2021).	Eurostat
	Greenhouse gases		Milestad et al. (2024), Mitova (2021), Nadaraja et al. (2021)	
Fertilizers	Nitrogen fertilizers	2012-2022	Mitova (2021), Nadaraja et al. (2021)	
	Phosphorus fertilizers		Mitova (2021), Nadaraja et al. (2021)	
Water	Water consumption	2012-2022	Milestad et al. (2024), Mitova (2021), Nadaraja et al. (2021)	
Land use	Area under organic farming	2012-2022	Mitova (2021).	
Energy	Energy content	2012-2022	Milestad et al. (2024), Mitova (2021), Nadaraja et al. (2021).	
Waste	Waste generation	2012-2022 (every two years)	Milestad et al. (2024), Mitova (2021).	

Source: compiled by the authors

Pearson correlation analysis is applied to identify linear relationships, followed by simple linear regression models to estimate the marginal effects of each indicator. Only statistically significant relationships ($p < 0.05$) are considered.

This approach is consistent with that used in prior empirical studies (e.g. Florea et al., 2021; Biagetti et al., 2025), in which regression models were employed to quantify the linkages between sustainability and productivity.

Results

To evaluate agricultural performance in the Baltic States, the analysis relies on the value of agricultural output over the period 2012–2022 (Figure 6.3).

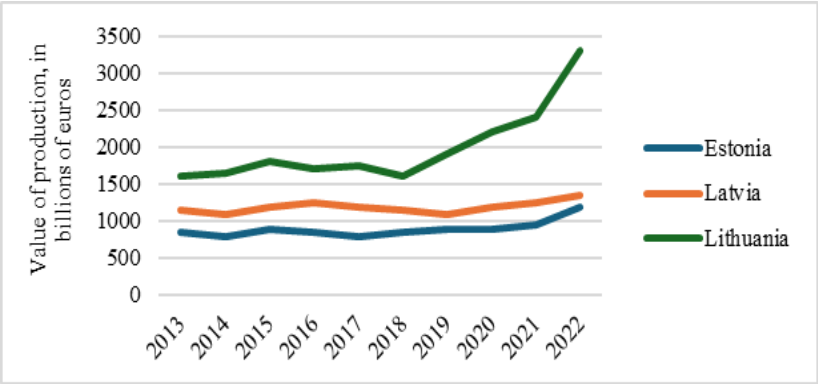


Figure 6.3 Agricultural output in the Baltic States (2012–2022)
Source: compiled by the authors

The data reveal notable differences in productivity dynamics across countries. Estonia exhibits higher volatility in output values, whereas Latvia demonstrates consistently higher production levels, with output on average 1.86 times greater than that of Estonia. Lithuania follows a similar trajectory to Latvia, with synchronized fluctuations observed across both countries. Notably, common growth peaks are identified in 2015, 2019, and 2022, suggesting the presence of shared external or structural drivers affecting agricultural performance in the region.

To examine the relationship between environmental sustainability indicators and agricultural productivity, Pearson correlation analysis was conducted (Table 6.8).

The results indicate substantial heterogeneity between countries in the strength and direction of relationships.

In Estonia and Latvia, for example, a moderate negative correlation was observed between ammonia emissions and agricultural output ($r = -0.60$ and $r = -0.59$, respectively), suggesting that higher emissions are not directly associated with increased

productivity. Conversely, greenhouse gas emissions exhibit a strong positive correlation with output in both countries (r = 0.67 in Estonia and r = 0.80 in Latvia), suggesting that higher production levels are closely linked to more intensive farming practices. This relationship is not observed in Lithuania, where the correlation is negligible.

Table 6.8

Correlation coefficients between agricultural output and environmental indicators

	Agricultural production in Estonia	Agricultural production in Latvia	Agricultural production in Lithuania
Ammonia emissions	**-0,60**	**-0,59**	-0,28
Greenhouse gases	**0,67**	**0,80**	0,05
Nitrogen fertilizers	**0,60**	**0,69**	-0,31
Nitrogen fertilizers	0,30	0,49	-0,25
Water consumption	0,16	0,36	0,08
Area under organic farming	**0,57**	**0,70**	**0,64**
Energy content	**-0,71**	**0,65**	**0,86**
Waste generation	**0,63**	-0,22	-0,32

Source: compiled by the authors

Similarly, the use of nitrogen fertilisers shows a strong positive relationship with productivity in Estonia and Latvia, while in Lithuania there is a weak negative association, implying a potentially different production structure or a transition towards less input-intensive agriculture. Phosphorus fertilisers and water consumption exhibit weak or negligible relationships across all countries and are therefore excluded from further analysis.

The organic farming area is positively associated with agricultural output in all three countries. The strongest relationship is observed in Latvia (r = 0.70), followed by Lithuania (r = 0.64) and Estonia (r = 0.57). This suggests that expanding organic farming does not necessarily hinder productivity and may contribute to output growth. Energy consumption reveals divergent patterns: a strong negative relationship is evident in Estonia (r = -0.71), while positive relationships are evident in Latvia (r = 0.65) and Lithuania (r = 0.86). This indicates different levels of technological efficiency and energy

use across the countries. Waste generation shows inconsistent and generally weak relationships and is therefore excluded from subsequent analysis.

Impact of Environmental Indicators on Agricultural Output in Estonia

Regression analysis was conducted using agricultural output as the dependent variable and the most strongly correlated environmental indicators as independent variables. The results indicate that only greenhouse gas emissions, nitrogen fertilizer use, and energy consumption have statistically significant effects on output ($p < 0.05$).

The estimated regression models are:

- $PV = 136.696 + 36.504 \times GHG$
- $PV = -323.98 + 0.0204 \times NF$
- $PV = 1226.527 - 6.603 \times EC$

where:

– PV – production value;
– GHG - greenhouse gas emissions;
– NF - nitrogen fertilizers;
– OFA - organic farming area;
– EC - energy consumption;

The findings reveal that greenhouse gas emissions and nitrogen fertilizer use have a positive and statistically significant impact on agricultural output, suggesting that higher productivity in Estonia is associated with more intensive agricultural practices. In contrast, energy consumption exhibits a significant negative effect, indicating potential inefficiencies in energy use or structural differences in production technologies.

Impact of Environmental Indicators on Agricultural Output in Latvia

In Latvia, regression analysis identifies four statistically significant determinants of agricultural output: greenhouse gas emissions, nitrogen fertilizer use, organic farming area, and energy consumption.

The estimated regression equations are:

- PV = -997.75 + 93.817 × GHG
- PV = -1090.9 + 0.0252 × NF
- PV = -161.7 + 75.832 × OFA
- PV = -243.8 + 6.2604 × EC

where:

– PV – production value;
– GHG - greenhouse gas emissions;
– NF - nitrogen fertilizers;
– OFA - organic farming area;
– EC - energy consumption;

All identified relationships are positive and statistically significant ($p < 0.05$), indicating that both intensive inputs (fertilizers, emissions, energy) and sustainability-oriented practices (organic farming) contribute to productivity growth in Latvia. This suggests a hybrid development pattern, where productivity gains are driven by both intensification and structural transformation towards more sustainable practices.

Impact of Environmental Indicators on Agricultural Output in Lithuania

In Lithuania, regression results indicate that only two variables – organic farming area and energy consumption – have a statistically significant impact on agricultural output.

The estimated equations are:

- PV = 135.64 + 243.289 × OFA
- PV = -3797.045 + 52.304 × EC

where:

– PV – production value;
– EC - energy consumption;
– OFA - organic farming area;

EC – energy consumption Both relationships are positive and statistically significant, suggesting that agricultural productivity in Lithuania is increasingly linked to structural changes, particularly the expansion of organic farming and increased energy use. Compared to Estonia and Latvia, traditional intensification factors such as fertilizers and emissions do not play a significant role, indicating a different development trajectory.

Cross-country comparison

Overall, the results highlight distinct patterns across the Baltic States. Estonia and Latvia exhibit productivity models strongly associated with intensive agricultural inputs, particularly greenhouse gas emissions and fertilizer use. In contrast, Lithuania demonstrates a shift towards sustainability-oriented productivity, where organic farming and energy use play a more prominent role. These findings indicate that the relationship between environmental sustainability and agricultural productivity is not uniform across countries and reflects different stages of structural transformation within the agricultural sector.

The explanatory power of the models ranges from moderate to relatively strong (R^2 = 0.36–0.74), indicating that environmental indicators explain a substantial share of agricultural productivity variation, although other structural factors remain relevant.

Discussion

This study reveals substantial cross-country differences in environmental sustainability indicators and their impact on agricultural productivity in the Baltic States. Overall, the results corroborate previous studies indicating that agriculture contributes to environmental degradation while remaining highly sensitive to environmental conditions (Biagetti et al., 2025; German et al., 2017).

A key pattern that emerged from the analysis was the strong association between productivity and input intensification in Estonia and Latvia. In both countries, greenhouse gas emissions and nitrogen fertiliser use are positively related to agricultural output. This indicates that higher productivity is largely achieved through the increased use of environmentally intensive inputs. This finding is consistent with the work of Florea et al. (2021) and German et al. (2017), who emphasise that productivity growth in agriculture is frequently driven by increased input rather than efficiency improvements. However, this relationship also indicates a dependency on intensive farming practices that could generate long-term sustainability risks.

By contrast, Lithuania exhibits a different development trajectory. The results suggest that increased agricultural productivity is primarily associated with the expansion of organic farming and

energy use, rather than traditional intensification factors such as fertilisers and emissions, which are not statistically significant. This suggests a structural transition towards more sustainable agricultural practices, where productivity gains are less dependent on chemical inputs and more related to technological and organisational adjustments. This pattern aligns with literature emphasising the role of sustainable practices in enhancing long-term agricultural resilience (Kumar et al., 2023; Smith et al., 2019).

Energy consumption further highlights divergent national pathways. While Latvia and Lithuania demonstrate a positive relationship between energy use and productivity, suggesting that energy inputs reflect technological development, Estonia shows a negative relationship, indicating potential inefficiencies or structural mismatches in energy utilisation. This finding corroborates the argument of Huck et al. (2024) that energy intensity does not invariably lead to productivity increases and may instead indicate inefficiencies within agricultural systems.

Crucially, the results reveal a clear trade-off between productivity and environmental sustainability. In Estonia and Latvia, for example, higher agricultural output is associated with increased emissions and resource use, suggesting that productivity gains come at the expense of environmental pressure. This trade-off highlights the difficulty of balancing short-term productivity goals with long-term sustainability objectives and emphasises the importance of policy interventions that promote efficiency rather than intensification.

From a policy perspective, the findings imply that a one-size-fits-all approach to agricultural sustainability is inappropriate for the Baltic region. Instead, policy measures should be tailored to country-specific development patterns. In Estonia and Latvia, for example, efforts should focus on reducing input intensity, improving resource efficiency and promoting environmentally friendly technologies. In Lithuania, meanwhile, policies should support the continued expansion of organic farming and sustainable agricultural practices, as these appear to boost productivity without putting additional strain on the environment.

However, the study is subject to several limitations. Firstly, the use of simple linear regression models does not capture potential interactions between multiple sustainability indicators. Secondly, the

analysis relies on secondary data, which may not fully reflect structural and institutional differences between countries. Future research could use panel data methods or more advanced econometric techniques to better capture dynamic relationships and causal effects.

Conclusions

This study provides a comparative econometric analysis of the relationship between environmental sustainability indicators and agricultural productivity in the Baltic States. The results show that these relationships are not consistent across countries, but instead reflect different structural development patterns.

In Estonia and Latvia, the findings suggest that agricultural productivity is primarily driven by input-intensive factors, such as greenhouse gas emissions, nitrogen fertiliser use and energy consumption. This suggests that productivity gains in these countries are closely linked to intensification processes, which could present challenges for long-term environmental sustainability. By contrast, Lithuania is on a different trajectory, with productivity being more strongly associated with the expansion of organic farming and energy use. This indicates a gradual transition towards more sustainable agricultural practices.

From a policy perspective, the results emphasise the need for differentiated strategies. In Estonia and Latvia, policy interventions should prioritise reducing environmental externalities by improving input efficiency and promoting low-emission agricultural technologies. In Lithuania, supporting organic farming and sustainable production models could enhance productivity while maintaining environmental performance.

Overall, the findings suggest that achieving sustainable agricultural growth in the Baltic States necessitates striking a balance between productivity goals and environmental limitations. This can be accomplished by implementing targeted, country-specific policy measures that address the unique structural characteristics of each agricultural system. Future research should build on this analysis by incorporating panel data methods and additional explanatory variables to explore the relationship between sustainability and productivity in agriculture more broadly across different regions.

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SUSTAINABLE DEVELOPMENT SYNERGY AND SECURITY: THEORETICAL AND METHODOLOGICAL FOUNDATIONS AND PRACTICAL IMPERATIVES OF ECONOMIC, SOCIAL, AND ENVIRONMENTAL TRANSFORMATION AND INCLUSION

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Sustainable development synergy and security: theoretical and methodological foundations and practical imperatives of economic, social, and environmental transformation and inclusion. Scientific monograph. – Plovdiv: ANIS Academic Publishing House, 2026. – Vol. 2. – 551 p.

The scientific monograph presents a comprehensive interdisciplinary analysis of sustainable development in the context of contemporary global challenges and security imperatives. The study explores the theoretical, methodological, and practical dimensions of achieving sustainable, inclusive, and secure development through the integration of economic, social, environmental, and institutional transformation processes. Particular attention is devoted to the development of conceptual approaches that facilitate the identification of synergies among the SDGs and enhance the effectiveness of governance mechanisms at local, national, and international levels. The authors investigate the key drivers, challenges, and opportunities associated with economic transformation, emphasizing the role of innovation, digitalization, green growth, circular economy principles, and resilience-building in promoting sustainable and secure economic development. The social dimension of sustainable development is examined through the lenses of equity, inclusion, human capital development, social cohesion, and social security, highlighting their significance for societal well-being and long-term stability. The scientific monograph proposes methodological approaches and practical recommendations for strengthening institutional capacity, improving strategic planning, fostering stakeholder engagement, and enhancing policy coherence in support of sustainable and inclusive transformation.

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