

Article

Evaluating Agri-Environmental Indicators for Land Use Impact in Baltic Countries Using Multi-Criteria Decision-Making and Eurostat Data

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Abstract: The present research assesses the agri-environmental sustainability of the Baltic states, namely Lithuania, Latvia, and Estonia, while analyzing agricultural biodiversity, greenhouse gas emissions, land utilization, energy use, and water management. For the purpose of these evaluations and ranking, we employ the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), applied to a set of agri-environmental indicators (AES) collected from various sources, including Eurostat and similar databases. This knowledge is necessary to help policymakers or agricultural managers who are interested in developing more sustainable agriculture in the region. That is why, according to the findings, the highest AES value is attributed to Latvia, followed by Lithuania and Estonia. Conservation methods that were essential included High-Nature-Value farmland, bird populations in agricultural habitats, organic farming, and water. It emphasizes the use of Multi-Criteria Decision Making tools for combining both qualitative and quantitative data and form the general framework for sustainability assessment. Another goal of this research is to fill the gap in the literature regarding the lack of attention paid to agri-environmental sustainability in the Baltic area in general. This, therefore, suggests that assessing the strengths or weaknesses of these nation-states provides critical information that can inform the change of land management practices, nutrition practices in agriculture, and the ability of the natural world to adapt. The findings will be useful to governmental leaders and individuals involved in agriculture who need to find a balance between economic growth and conservation, as well as scholars working to improve the international measures for agri-environmental assessment.

Keywords: agri-environmental sustainability; Baltic countries; multi-criteria decision-making (MCDM); TOPSIS; land use indicators



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1. Introduction

Agriculture plays a crucial role in the economic and environmental landscape of the Baltic States of Lithuania, Latvia, and Estonia, where sustainable land use is vital for maintaining soil fertility, supporting biodiversity, and reducing greenhouse gas emissions [1,2]. However, the evaluation of agricultural–environmental interactions requires tailored approaches, especially in regions like the Baltics, where agricultural practices and environmental pressures vary significantly [3].

The increasing pressure to balance agricultural productivity with environmental sustainability in the Baltic countries highlights the need for systematic evaluation tools. While EU policies such as the Common Agricultural Policy (CAP) emphasize environmental conservation, there is insufficient understanding of how these policies translate into measurable outcomes at the national level. This gap limits policymakers’ ability to implement

effective land use strategies. Therefore, this study addresses this issue by evaluating agri-environmental indicators (AEIs) to enhance decision-making and promote sustainable agricultural practices in the Baltic region.

Agro-environmental indicators have been proposed as a mechanism to clarify the relationship between agriculture and the environment, which enables the evaluation of conditions and developments in this area towards sustainable development [4]. These indicators cover a broader set of attributes, including land use, biodiversity, soil quality, aquatic health, and more, with the goal of reducing the effects of greenhouse gases. In the context of the Baltic States, the importance of AEI is increasing due to the growing pressure to implement EU directives, such as those on the Common Agricultural Policy, which oblige member states to adopt agricultural practices to promote environmental sustainability [5]. Given the disparity in agricultural intensity and environmental pressures across the Baltic States, the application of a standard set of criteria provides a basis for evaluating and comparing sustainability-enhancing activities [6].

However, there is a lack of understanding as to which of the existing AEIs is most suitable for assessing the effects of agricultural land use in the Baltic. This ambiguity is a challenge for policymakers and stakeholders in making decisions about sustainable land use [7]. The complexity of land use impact requires consideration of various physical elements, including soil fertility, crop types, land cover changes, and environmental protection efforts, leading to multiple indicator choices [8]. A complete evaluation of AEIs in this field requires a methodological framework that can accommodate many and often inconsistent criteria. Standardized evaluation methodologies may not be sufficient to capture the complexity of such assessments. Therefore, the relevance of the MCDM technique in this research [9].

The aim of this research is to rank the AEI in the Baltic States based on their impact on land use, using the MCDM approach and Eurostat data. As a result, the aim of this research is to develop a model using MCDM to identify the main variables that effectively show the impact of land use in different agricultural and environmental conditions. EUROSTAT, the statistical agency of the European Union, provides a valuable repository of standardized data on agriculture and the environment, facilitating comparisons between Lithuania, Latvia, and Estonia. This dataset provides a basis for understanding how some selected AEIs can help promote sustainable land use policy in the Baltic region.

This study aims to answer the following key research questions:

1. Which agri-environmental indicators are most relevant for assessing the sustainability of agricultural land use in the Baltic States?
2. How do Lithuania, Latvia, and Estonia compare in terms of sustainability based on these indicators?
3. What policy recommendations can be derived from the findings to support sustainable land management practices in the region?

This article adheres to a defined framework to achieve its objectives: Initially, literature reviews on AEIs and MCDM methodologies are presented. This review establishes the foundation for the current study and highlights prior difficulties in evaluating land use impact via agri-environmental indicators. Following the literature review, the methodology portion of this research delineates the MCDM methodologies employed to classify the factors influencing the environmental and socio-economic impact of land use, along with the selection criteria and weights specified below. Consequently, by employing MCDM techniques, the authors can ascertain the priorities of indicators deemed most appropriate for analyzing agricultural land usage in each Baltic nation.

The theoretical basis for this study is grounded in the principles of sustainability science, which emphasize the integration of environmental, economic, and social dimensions for informed decision-making. Multi-Criteria Decision-Making (MCDM) methodologies, such as the TOPSIS technique used in this study, provide a structured approach to evaluating complex, multidimensional sustainability challenges. By applying these methods

to agri-environmental indicators, this research builds on existing frameworks to offer a region-specific evaluation model for the Baltic States.

Multi-Criteria Decision-Making (MCDM) methods, including TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), have been widely applied in various contexts to evaluate sustainability and land use impacts. For instance, Pathak et al. (2020) utilized TOPSIS to prioritize sustainability indicators for agricultural development in India, integrating environmental, social, and economic factors [10]. Similarly, Streimikis et al. (2024) applied MCDM to assess agri-environmental sustainability in Baltic states, highlighting the importance of biodiversity and energy efficiency indicators [6]. These examples demonstrate the versatility and robustness of MCDM methods in addressing complex decision-making problems in agricultural and environmental management. This study builds on these foundations by applying TOPSIS to evaluate and rank agri-environmental indicators in the Baltic region, offering insights specific to Lithuania, Latvia, and Estonia.

Unlike previous studies that have largely focused on individual agri-environmental indicators or generalized regional sustainability assessments, this paper provides a comprehensive, data-driven analysis of the Baltic States using the TOPSIS method. By integrating Eurostat data with expert evaluations, this study offers a novel approach to prioritizing indicators and tailoring policy recommendations, addressing a critical gap in the literature on regional sustainability assessments.

The results section includes a comparison of AEIs and a discussion of the relative significance of several variables for assessing their impact on land use in Lithuania, Latvia, and Estonia. Policymakers and environmental agencies can utilize this ranking to determine the most appropriate indicators that reflect the influence of agriculture on land use, hence facilitating informed policy decisions about sustainable land use. The findings of the paper, while acknowledging substantial regional disparities, indicate the necessity to build country-specific Agricultural and Environmental Indicator (AEI) frameworks to enable each nation to attain the requisite advancements in agricultural and environmental management.

This research enhances the existing knowledge of sustainable agriculture and environmental policy by offering a method to evaluate agri-environmental indicators in the Baltic region. This investigation, utilizing MCDM and Eurostat data, enhanced the comprehension of AEIs, particularly concerning land usage, and provided guidance for policymakers aiming to enhance sustainability in agricultural systems. The concluding section of this work highlights the significance of these findings and proposes recommendations for future research aimed at enhancing the indicator-based evaluation of additional environmental impacts beyond land use. This framework maintains the study's flexibility and relevance to continuing developments in the field of sustainable land (SL) management in the Baltic region and beyond.

2. Background of Study

This study recognizes that environmental conservation is intrinsically linked to the pursuit of green agriculture, ensuring sustainable land usage. As global populations increase, the resulting strain on natural resources has made optimal land utilization a critical focus for policy, academic inquiry, and the agricultural sector [11]. Agricultural Environmental Indicators (AEI) function as essential tools for assessing land use sustainability, encompassing aspects such as environmental conditions, resource efficiency, and biological diversity. The chosen indicators include agricultural land, arable land, forest area, and landscape fragmentation, analyzed using Multi-Criteria Decision-Making (MCDM) methodologies and Eurostat data [12].

The MCDM approach, particularly the TOPSIS technique, enables the prioritization of sustainability factors by evaluating ecological, economic, and social dimensions. It provides a methodologically robust foundation for analyzing the environmental impact of different land use types, such as agricultural, forested, or urban land in the Baltic states, while facilitating a comparative assessment across Lithuania, Latvia, and Estonia based on consistent temporal trends in environmental sustainability [13,14].

The Baltic nations have pursued agricultural intensification strategies to meet the growing demand for food production and enhance food exports [1]. While intensive practices involving fertilizers, pesticides, and monoculture systems initially boosted productivity, they have led to soil fertility depletion, erosion, nutrient pollution, and decreased biodiversity. These unsustainable methods raise significant concerns about long-term agricultural sustainability [15,16].

Over the past three decades, shifts toward market economies in the Baltic countries have resulted in changes in land use patterns [17]. Economic modernization, agricultural production growth, urban expansion, and forestry practices have simultaneously fostered prosperity and imposed environmental limitations. These include soil degradation, water shortages, and biodiversity loss, further exacerbated by climate change, rising temperatures, and strained natural resources [18].

Urbanization of agricultural and rural areas in the Baltic region has significantly altered land conditions [1]. The replacement of arable land with urban developments, including residential and industrial zones, leads to habitat fragmentation, green deserts, and conflicts between agricultural practices and urbanization. This transformation restricts opportunities for sustainable agriculture and the integration of conservation-focused methods [19].

Climate change presents ongoing challenges for Baltic agriculture, impacting horticulture and barren areas due to rising temperatures and shifts in precipitation patterns. These changes reduce crop yields, disrupt growing seasons, and increase vulnerability to pests and diseases. Frequent rainfall, flooding, and drought events further contribute to soil erosion, water pollution, and field waterlogging, threatening food security and sustainability [20,21].

Forests in the Baltic region, known for their CO₂ sequestration and biodiversity preservation capacities, face significant threats from unsustainable forestry practices, including rapid deforestation and insufficient replanting [22,23]. When managed effectively, forests maintain biodiversity equilibrium and reduce soil erosion. However, climate change-induced weather variability poses additional challenges to forest resilience and ecosystem services [24].

AEI provides critical insights for developing sustainable land use policies and agricultural strategies in the Baltic nations. Indicators such as soil quality, water usage efficiency, biodiversity metrics, and greenhouse gas levels enable policymakers to evaluate the effectiveness of current practices and identify areas needing improvement. Utilizing MCDM tools enhances the analysis of these variables, guiding efforts to improve sustainable land utilization [25,26].

Soil health is a pivotal factor influencing agricultural growth, sea-terrestrial interfaces, and global temperatures. Indicators like organic matter content, soil pH, and nutrient classification provide valuable data to mitigate risks and promote sustainable agronomic practices. The overuse of fertilizers and pesticides, leading to declining soil quality and increased erosion, underscores the need for sustainable solutions [27,28].

AEI also facilitates stakeholder engagement by providing measurable data on agriculture's environmental impacts, fostering collaboration among farmers, lawmakers, environmental groups, and the public. This supports the adoption of technologies that balance food production with environmental protection [29,30].

Additionally, water use efficiency and energy consumption are critical in assessing agricultural sustainability. Inefficient irrigation systems and over-reliance on fossil fuels exacerbate environmental challenges, including soil salinization, water pollution, and high carbon emissions. Incorporating water and energy efficiency indicators into decision-making promotes resource conservation and reduces agriculture's ecological footprint [31–33].

Biodiversity conservation remains essential for maintaining stable agricultural systems. Indicators such as species richness, pollinator diversity, and habitat preservation guide the promotion of organic and agroecological practices. These approaches enhance pest

control, pollination, and nutrient cycling, which are critical for long-term agricultural sustainability [34,35].

This study emphasizes the importance of AEI in establishing sustainability targets, such as those outlined by the European Union’s Common Agricultural Policy (CAP). By implementing these indicators, member states can evaluate progress toward environmental goals, including biodiversity preservation, low-carbon practices, and ecosystem restoration [36,37].

This research aims to fill the gap in the literature regarding the lack of attention paid to agri-environmental sustainability in the Baltic area in general.

MCDM methodologies, especially TOPSIS, play a vital role in evaluating and ranking AEIs to identify optimal strategies for sustainable land management. By integrating Eurostat data with qualitative insights, this research provides a comprehensive framework for assessing land use impacts and developing actionable policies in the Baltic countries [38–40].

Eurostat, as the European Union’s statistical office, offers reliable and comparable agricultural and environmental data critical for this analysis. Indicators such as greenhouse gas emissions, land use changes, and irrigation practices allow for precise regional comparisons and insights into sustainable land management [41,42]. The indicators from Eurostat are shown in Table 1.

Table 1. Eurostat agri-environment indicators obtained from EUROSTAT.

Category	Code	Indicator	Resources
Biodiversity	C1	Agricultural areas under Natura 2000	European Environment Agency (EEA)
	C2	High-Nature-Value farmland	European Environment Agency (EEA)
	C3	Population trends of farmland birds	European Environment Agency (EEA)
Climate	C4	Greenhouse gas (GHG) emissions	European Environment Agency (EEA)
Environment	C5	General environmental care funding	Directorate-General for Agriculture and Rural Development (DG AGRI)
	C6	Land use change	European Environment Agency (EEA)
Land Use	C7	Cropping patterns	Eurostat
	C8	Soil cover	Eurostat
	C9	Intensification/extensification	Directorate-General for Agriculture and Rural Development (DG AGRI)
Energy	A10	Specialisation of land	Eurostat
	C11	Energy use	Eurostat
	A12	Production of renewable energy	Directorate-General for Agriculture and Rural Development (DG AGRI)
Societal Demands on Food and Health	C13	Reduce pesticide use	Eurostat
	C14	Area under organic farming	Eurostat
	C15	Pesticide consumption	Eurostat
	C16	Pesticide risk	Directorate-General for Health and Food Safety (DG SANTE)
Air Quality	C17	Ammonia emissions	European Environment Agency (EEA)
Soil Quality and Fertility	C18	Soil erosion	Joint Research Centre (JRC)
	C19	Tillage practices	Eurostat
Water Quality	C20	Mineral fertilizer consumption	Eurostat
	C21	Livestock patterns	Eurostat
	C22	Manure storage	Eurostat

Table 1. *Cont.*

Category	Code	Indicator	Resources
	C23	Gross nitrogen balance	Eurostat
	C24	Pollution risk from phosphorus	Eurostat
	C25	Nitrate pollution	European Environment Agency (EEA)
	C26	Pesticide pollution	European Environment Agency (EEA)
Water Quantity and Availability	C27	Irrigation	Eurostat
	C28	Water abstraction	European Environment Agency (EEA)

This research offers significant contributions by addressing agri-environmental challenges in the Baltic region, which has received limited attention in sustainability studies. Through a comprehensive evaluation of AEIs, this study informs policymakers, agricultural entities, and environmental organizations about strategies to optimize practices, mitigate environmental damage, and align with broader initiatives like the EU Green Deal and the UN Sustainable Development Goals (SDGs) [23,24].

3. Method

This study employs Multi-Criteria Decision-Making (MCDM) methodologies, specifically the TOPSIS method, to evaluate agri-environmental indicators. The detailed process, including the selection of criteria, normalization of data, weight assignment, and ranking, is comprehensively outlined in this section. As the methodologies are thoroughly explained here, additional references are not necessary. The Eurostat data, used to provide quantitative measures for the indicators, is appropriately cited to acknowledge the data source and ensure transparency.

Baseline data were collected from Eurostat, ensuring regional relevance and methodological consistency. The dataset includes critical indicators such as greenhouse gas emissions, soil quality, water use efficiency, biodiversity conservation, and land productivity. These indicators were chosen through a rigorous review of the existing literature and sustainability frameworks.

In this study, experts were selected based on their academic and professional expertise in areas directly relevant to the research objectives. Specifically, the panel comprised individuals with significant experience in agricultural economics, environmental science, and policy-making. This interdisciplinary approach ensured a comprehensive evaluation of agri-environmental indicators, combining technical, ecological, and practical insights. Selection criteria included peer-reviewed publications, involvement in relevant projects, and familiarity with sustainability challenges specific to the Baltic region. A comprehensive questionnaire was developed to gather expert input on the relative importance of the selected indicators. The experts, comprising agricultural economists and environmental scientists, were carefully selected to provide a balanced perspective on the evaluation of agri-environmental indicators. Their input ensured alignment with scientific principles and practical applications of sustainability. While policymakers were consulted during the initial phases to provide insights into regional priorities and policy constraints, they did not directly participate in the weighting process. This distinction ensures that the study remains scientifically robust while incorporating relevant policy considerations into its broader context.

Multi-Criteria Decision-Making (MCDM) methods are invaluable tools for addressing complex decision-making scenarios where multiple, often conflicting criteria must be evaluated simultaneously. In the context of agri-environmental sustainability, MCDM provides a systematic approach to integrating diverse qualitative and quantitative factors, enabling a comprehensive evaluation of indicators like biodiversity, greenhouse gas emissions, and water efficiency. Among various MCDM techniques, the Technique for Order Preference

by Similarity to Ideal Solution (TOPSIS) was chosen for this study due to its methodological simplicity, computational efficiency, and ability to rank alternatives based on their proximity to an ideal solution. Unlike other MCDM methods that might require extensive subjective input, TOPSIS balances objective data analysis with expert judgment, ensuring transparency and replicability. Moreover, its capability to handle both benefit and cost criteria makes it particularly suitable for assessing sustainability, where trade-offs between economic, environmental, and social dimensions are common. By applying TOPSIS, this study was able to provide actionable insights for policymakers, rank agri-environmental indicators effectively, and explore the relative performance of Baltic countries in a robust, data-driven manner solution [10].

Weights assigned to each indicator play a critical role in determining the final rankings, as they reflect the relative importance of each criterion in the context of regional sustainability priorities. The expert-assigned weights were derived from agricultural economists and environmental scientists to ensure a balanced perspective. To assess the impact of weighting, we also conducted a supplementary analysis with equal weights, comparing the rankings to those derived using expert-assigned weights. The comparison highlights how varying weights influence the prioritization of indicators and rankings, providing a sensitivity check for the robustness of our results.

The process for evaluating agri-environmental indicators begins with defining the research problem by identifying gaps in the literature and the need for assessing sustainability in agricultural practices within the Baltic region. Next, the study formulates clear objectives and research questions to guide the analysis. Data are then collected from reliable sources such as Eurostat and through expert input to ensure a comprehensive dataset. Subsequently, relevant agri-environmental indicators are selected, and their significance is assigned weights using expert evaluations. The Multi-Criteria Decision-Making (MCDM) method, specifically TOPSIS, is applied to rank the indicators based on their contribution to sustainability. To ensure robustness, sensitivity analysis is conducted, testing how changes in criterion weights impact the results. Finally, the findings are analyzed to provide insights into the relative sustainability performance of the Baltic States, and recommendations are made for policymakers and stakeholders to enhance agricultural sustainability and environmental practices. This structured approach ensures a thorough and transparent evaluation process.

Figure 1 shows the research process. The process for evaluating agri-environmental indicators begins with defining the research problem by identifying gaps in the literature and the need for assessing sustainability in agricultural practices within the Baltic region. Next, the study formulates clear objectives and research questions to guide the analysis. Data are then collected from reliable sources such as Eurostat and through expert input to ensure a comprehensive dataset. Subsequently, relevant agri-environmental indicators are selected, and their significance is assigned weights using expert evaluations. The Multi-Criteria Decision-Making (MCDM) method, specifically TOPSIS, is applied to rank the indicators based on their contribution to sustainability. To ensure robustness, sensitivity analysis is conducted, testing how changes in criteria weights impact the results. Finally, the findings are analyzed to provide insights into the relative sustainability performance of the Baltic States, and recommendations are made for policymakers and stakeholders to enhance agricultural sustainability and environmental practices. This structured approach ensures a thorough and transparent evaluation process.

The TOPSIS method was employed to prioritize the indicators based on their significance to sustainability. This method evaluates each indicator's proximity to an ideal solution, enabling a structured ranking of land use practices. By integrating expert evaluations with Eurostat data, the study provides a robust framework for analyzing and comparing the environmental and agricultural impacts across the three Baltic nations.

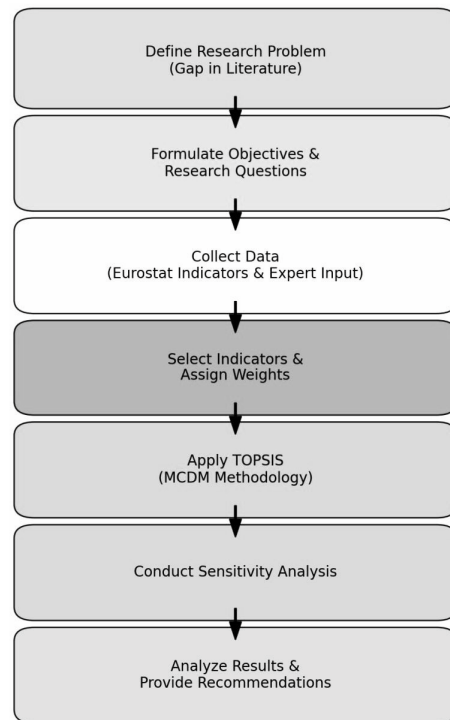


Figure 1. Research process framework.

TOPSIS.

Step 1: Construct the Decision Matrix.

The first step is to construct the decision matrix $X = [X_{ij}]$, where each element X_{ij} represents the performance of alternative A_i under criterion C_j it shows in Equation (1)

$$X = [x_{ij}]_{n \times m} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \quad (1)$$

Step 2: Normalize the Decision Matrix.

Normalize the decision matrix using the following formula Equation (2):

$$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^I x_{ij}^2} \quad (2)$$

where r_{ij} is the normalized value for alternative A_i under criterion C_j .

Step 3: Construct the Weighted Normalized Decision Matrix.

Multiply each element of the normalized decision matrix by the corresponding criteria weight shows in Equation (3):

$$v_{ij} = W_j * y_{ij}; (i = 1, 2, \dots, I; j = 1, 2, \dots, J) \quad (3)$$

where v_{ij} is the weighted normalized value for alternative A_i under criterion C_j .

Step 4: Determine the Positive Ideal and Negative Ideal Solutions.

The positive ideal solution A^+ and the negative ideal solution A^- are defined as

$$A^+ = [v_1^+, v_2^+, \dots, v_j^+] \quad (4)$$

$$A^- = [v_1^-, v_2^-, \dots, v_j^-]$$

where

$$v_j^+ = \begin{cases} \max v_{ij}, & \text{if } j \text{ is a benefit attribute} \\ \min v_{ij}, & \text{if } j \text{ is a cost attribute} \end{cases}$$

$$v_j^- = \begin{cases} \min v_{ij}, & \text{if } j \text{ is a benefit attribute} \\ \max v_{ij}, & \text{if } j \text{ is a cost attribute} \end{cases}$$

where J benefit is the set of benefit criteria and J cost is the set of cost criteria.

Step 5: Calculate the Separation Measures.

Calculate the separation of each alternative from the positive ideal solution S_i^+ and the negative ideal solution S_i^- using the Euclidean distance can be find in Equation (5):

$$S_i^+ = \sqrt{\sum_{j=1}^J (v_{ij} - v_j^+)^2} \quad (5)$$

$$S_i^- = \sqrt{\sum_{j=1}^J (v_{ij} - v_j^-)^2}$$

Step 6: Calculate the Relative Closeness to the Ideal Solution.

Calculate the relative closeness of each alternative to the ideal solution shows as Equation (6):

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad (6)$$

where C_i^* is the relative closeness of alternative a_i to the ideal solution.

Step 7: Rank the Alternatives.

Finally, rank the alternatives based on their C_i^* values. The higher the C_i^* , the closer the alternative is to the ideal solution, and thus, the better the alternative.

4. Result

The Initial Matrix, shown in Table 2, showcases the raw data for 28 agri-environmental indicators (AEIs) across Lithuania, Latvia, and Estonia. Each value represents the score assigned to a criterion, reflecting the countries' relative sustainability performance. Higher values denote better outcomes, such as effective environmental care or efficient resource use. From this table, it is evident that Latvia excels in certain biodiversity and environmental indicators, such as areas under organic farming (C14) and High-Nature-Value farmland (C2). In contrast, Estonia lags in key areas like greenhouse gas emissions (C4) and pesticide use (C15), which are critical for sustainable agricultural practices. The sum of squared scores is calculated for each criterion to emphasize differences and refine the data for meaningful comparisons. This process helps to highlight variations across the indicators. The analysis aims to assess each country's performance in critical sustainability dimensions.

Table 3 presents the normalized matrix, which refines the data by eliminating differences in scale, allowing for a fair comparison of sustainability performance across indicators. The results reveal distinct trends among the Baltic countries. Latvia demonstrates notable strength in specific indicators of biodiversity conservation (e.g., C3: Farmland bird populations, C2: High-Nature-Value farmland) and soil management (e.g., C18: Soil erosion prevention), which highlight its leadership in these areas of sustainability. However, its performance across other indicators, such as water quality and nitrate pollution (C25), indicates room for further improvement. This suggests that Latvia's leadership is limited to certain aspects rather than reflecting comprehensive sustainability across all evaluated metrics.

In contrast, Estonia shows variability, excelling in certain biodiversity metrics (e.g., C14: Area under organic farming) but facing challenges with nitrate pollution (C25) and greenhouse gas emissions (C4). Lithuania, while balanced with moderate scores across most indicators, lacks the standout strengths observed in Latvia, suggesting opportunities for further improvement in areas like biodiversity (C3) and soil quality (C19: Tillage practices).

This normalized analysis provides a clearer understanding of each country's sustainability performance, emphasizing both strengths and areas for improvement.

Table 2. Initial Matrix.

Initial Matrix	Lithuania (A1)	Latvia (A2)	Estonia (A3)	Sum of Square	SQRT
C1	4	5	3	50	7.0711
C2	5	4	5	66	8.124
C3	3	4	3	34	5.831
C4	4	4	4	48	6.9282
C5	3	3	2	22	4.6904
C6	5	4	5	66	8.124
C7	4	3	4	41	6.4031
C8	5	5	4	66	8.124
C9	4	3	5	50	7.0711
C10	2	3	2	17	4.1231
C11	3	3	4	34	5.831
C12	5	4	5	66	8.124
C13	4	5	4	57	7.5498
C14	4	4	3	41	6.4031
C15	2	3	3	22	4.6904
C16	4	4	4	48	6.9282
C17	3	3	2	22	4.6904
C18	5	5	4	66	8.124
C19	3	4	3	34	5.831
C20	4	3	3	34	5.831
C21	3	2	2	17	4.1231
C22	4	3	3	34	5.831
C23	5	4	5	66	8.124
C24	4	5	4	57	7.5498
C25	5	4	5	66	8.124
C26	3	4	3	34	5.831
C27	4	4	5	57	7.5498
C28	5	5	4	66	8.124

Referring to Table 4, the Normalized Weighted Matrix further incorporates the importance of each indicator through equal weighting. This approach emphasizes the contribution of each criterion to the overall sustainability ranking, maintaining fairness in the evaluation. Latvia's steady performance in biodiversity-related metrics, such as farmland bird populations and areas under Natura 2000, strengthens its position as the leader. Lithuania remains close behind, benefiting from a balanced approach to land use and energy efficiency. Estonia's lower scores in certain critical areas, such as pesticide use and water quality, reinforce its third-place position.

Table 5 presents the values for S_i^+ (distance to the positive ideal solution) and S_i^- (distance to the negative ideal solution) for each alternative (A1, A2, A3). A1, A2, and A3 represent the sustainability performance of Lithuania, Latvia, and Estonia, respectively.

Table 3. Normalized matrix.

Normalized Matrix	A1	A2	A3
C1	0.5657	0.7071	0.4243
C2	0.6155	0.4924	0.6155
C3	0.5145	0.686	0.5145
C4	0.5774	0.5774	0.5774
C5	0.6396	0.6396	0.4264
C6	0.6155	0.4924	0.6155
C7	0.6247	0.4685	0.6247
C8	0.6155	0.6155	0.4924
C9	0.5657	0.4243	0.7071
C10	0.4851	0.7276	0.4851
C11	0.5145	0.5145	0.686
C12	0.6155	0.4924	0.6155
C13	0.5298	0.6623	0.5298
C14	0.6247	0.6247	0.4685
C15	0.4264	0.6396	0.6396
C16	0.5774	0.5774	0.5774
C17	0.6396	0.6396	0.4264
C18	0.6155	0.6155	0.4924
C19	0.5145	0.686	0.5145
C20	0.686	0.5145	0.5145
C21	0.7276	0.4851	0.4851
C22	0.686	0.5145	0.5145
C23	0.6155	0.4924	0.6155
C24	0.5298	0.6623	0.5298
C25	0.6155	0.4924	0.6155
C26	0.5145	0.686	0.5145
C27	0.5298	0.5298	0.6623
C28	0.6155	0.6155	0.4924

Table 4. Normalized weighted matrix.

Normalized Weighted Matrix	A1	A2	A3
C1	0.0202	0.0253	0.0152
C2	0.022	0.0176	0.022
C3	0.0184	0.0245	0.0184
C4	0.0206	0.0206	0.0206
C5	0.0228	0.0228	0.0152
C6	0.022	0.0176	0.022
C7	0.0223	0.0167	0.0223
C8	0.022	0.022	0.0176
C9	0.0202	0.0152	0.0253
C10	0.0173	0.026	0.0173

Table 4. Cont.

Normalized Weighted Matrix	A1	A2	A3
C11	0.0184	0.0184	0.0245
C12	0.022	0.0176	0.022
C13	0.0189	0.0237	0.0189
C14	0.0223	0.0223	0.0167
C15	0.0152	0.0228	0.0228
C16	0.0206	0.0206	0.0206
C17	0.0228	0.0228	0.0152
C18	0.022	0.022	0.0176
C19	0.0184	0.0245	0.0184
C20	0.0245	0.0184	0.0184
C21	0.026	0.0173	0.0173
C22	0.0245	0.0184	0.0184
C23	0.022	0.0176	0.022
C24	0.0189	0.0237	0.0189
C25	0.022	0.0176	0.022
C26	0.0184	0.0245	0.0184
C27	0.0189	0.0189	0.0237
C28	0.022	0.022	0.0176

Table 5. Amount of Si+ and Si−.

Alternatives	Si+	Si−
A1	0.0200	0.0231
A2	0.0210	0.0244
A3	0.0263	0.0186

A2 (Latvia) has the smallest Si+ (0.0210) and the largest Si− (0.0244), indicating it is closest to the ideal solution and ranks highest in sustainability.

A1 (Lithuania) follows with Si+ of 0.0200 and Si− of 0.0231, showing it is slightly behind Latvia.

A3 (Estonia) has the largest Si+ (0.0263) and the smallest Si− (0.0186), indicating it is furthest from the ideal solution and ranks lowest.

The Ideal Solutions and Relative Closeness (Ci) shown in Table 6 identify Latvia as the top performer with a relative closeness (Ci) of 0.538, narrowly ahead of Lithuania at 0.536. Estonia, with a Ci of 0.415, ranks third. This analysis underscores Latvia's ability to maintain high standards across diverse sustainability criteria. Lithuania's close ranking reflects its strengths in energy efficiency and biodiversity, while Estonia's weaker performance in environmental indicators highlights the need for targeted interventions to improve sustainability.

Table 6. Final ranking.

Alternatives	Ci	Ranking
A1	0.536	2
A2	0.538	1
A3	0.415	3

These findings offer valuable insights for policymakers and stakeholders. Latvia's leading position suggests its practices could serve as benchmarks for the other Baltic countries. For Lithuania, a focus on enhancing biodiversity and reducing emissions could further boost its ranking. Estonia, on the other hand, must prioritize improving water and soil quality while addressing nitrate pollution to catch up with its neighbors. The results provide a foundation for informed decision-making and strategic planning in advancing agricultural sustainability in the Baltic region.

Final Ranking.

The final ranking results reveal Latvia as the best performer ($C_i = 0.538$), closely followed by Lithuania ($C_i = 0.536$), with Estonia ranking third ($C_i = 0.415$). The narrow margin between Latvia and Lithuania highlights the sensitivity of the rankings to small variations in indicator values. Estonia's lower score reflects challenges in key indicators such as greenhouse gas emissions and pesticide use, although it demonstrates strengths in areas like organic farming and biodiversity conservation.

Based on the C_i values, the agri-environmental sustainability ranking of the Baltic countries is as follows:

- Latvia: $C_i = 0.538$ (Best performer);
- Lithuania: $C_i = 0.536$ (Second place);
- Estonia: $C_i = 0.415$ (Third place).

This systematic evaluation of agri-environmental indicators provides a clear ranking of the Baltic countries and offers valuable insights for policymakers. The results can guide efforts to enhance sustainability in the agricultural sector by addressing specific weaknesses and building on each country's strengths.

Sensitive Analysis.

The Sensitivity Analysis examines how changes in the weights assigned to the different criteria affect the ranking of the countries. In this study, we assumed that all criteria were equally weighted (with a weight of 1 for each). However, in real-world applications, the importance of each criterion can vary depending on the specific priorities or policy goals. Sensitivity analysis helps us understand how robust the rankings are to changes in these weights.

Sensitivity Analysis and Results Discussion.

Introduction to Sensitivity Analysis.

Sensitivity analysis was performed to evaluate the robustness of the results obtained through the TOPSIS method. This analysis involved adjusting the weights of specific criteria to simulate different priority scenarios. The objective was to understand how changes in weight allocations impact the ranking of Lithuania, Latvia, and Estonia in terms of agri-environmental sustainability.

Scenarios and Results.

Scenario 1: Increased Weight for Environmental Criteria.

In this scenario, criteria related to environmental sustainability, such as greenhouse gas emissions, soil erosion, and water pollution, were assigned higher weights.

- Closeness Coefficients (C_i):
 - Lithuania: 0.553;
 - Latvia: 0.594;
 - Estonia: 0.376.
- Ranking:
 - Latvia;
 - Lithuania;
 - Estonia.

Observation: Latvia ranked first due to its stronger performance in reducing environmental impacts and managing natural resources effectively. Lithuania performed reasonably well, but Estonia's performance lagged behind, possibly due to specific environmental challenges.

Scenario 2: Increased Weight for Economic Sustainability.

This scenario prioritized criteria related to economic aspects, such as land use efficiency, cropping patterns, and production costs.

- Closeness Coefficients (C_i):

- Lithuania: 0.491;
- Latvia: 0.492;
- Estonia: 0.484.

- Ranking:

- Latvia;
- Lithuania;
- Estonia.

Observation: The rankings in this scenario were closer, indicating that the Baltic countries have comparable performances in economic sustainability. However, Latvia maintained its lead, reflecting a balanced approach between economic and environmental aspects.

Scenario 3: Increased Weight for Biodiversity and Ecological Balance.

This scenario gave higher priority to criteria such as High Nature Value farmland, population trends of farmland birds, and areas under Natura 2000.

- Closeness Coefficients (C_i):

- Lithuania: 0.516;
- Latvia: 0.549;
- Estonia: 0.419.

- Ranking:

- Latvia;
- Lithuania;
- Estonia.

Observation: Latvia's biodiversity management and ecological conservation practices contributed to its top ranking. Lithuania showed moderate performance, while Estonia's lower scores highlighted room for improvement in biodiversity conservation.

Key Insights and Discussion.

1. Latvia's Consistent Performance:

Latvia ranked first across all scenarios, indicating robust sustainability practices regardless of the prioritization of specific criteria.

2. Lithuania's Moderate Strengths:

Lithuania consistently ranked second, demonstrating strong but slightly less balanced performance compared to Latvia.

3. Estonia's Room for Improvement:

Estonia ranked third in all scenarios, suggesting the need to enhance performance, particularly in biodiversity and environmental criteria.

The sensitivity analysis demonstrates that Latvia is the most sustainable among the Baltic countries in agri-environmental practices, followed by Lithuania and Estonia. Latvia's consistent performance across scenarios highlights its ability to balance environmental, economic, and biodiversity priorities effectively. These findings provide valuable insights for policymakers aiming to enhance sustainable agricultural practices in the Baltic region.

5. Discussion

This study assessed and ranked the agri-environmental sustainability of the Baltic countries using a multi-criteria decision-making approach. By applying the TOPSIS method, we evaluated each country based on its proximity to an ideal sustainability outcome, incorporating a comprehensive set of indicators spanning environmental, economic, and

biodiversity dimensions. The findings revealed that Latvia emerged as the top-performing country, followed by Lithuania and Estonia. Sensitivity analysis confirmed the robustness of these results, showing consistent rankings across various scenarios with different weightings of criteria. These outcomes highlight notable differences in the sustainability strategies and performances of the Baltic countries, underscoring areas for targeted improvement.

The methodology of this study was both systematic and comprehensive. By integrating quantitative data from reliable sources like Eurostat with qualitative assessments of indicator importance, the research ensured a balanced evaluation. The use of the TOPSIS method enabled a structured and clear ranking of sustainability performance, while sensitivity analysis tested the reliability of the results against shifts in indicator weightings. This combination of approaches allowed for a nuanced understanding of sustainability in the region, providing a foundation for practical recommendations to policymakers.

The agri-environmental indicators analyzed in this study play a pivotal role in understanding and improving sustainability. Indicators related to greenhouse gas emissions and nitrate pollution highlight the ecological impacts of agriculture and underscore the need for mitigation strategies. Biodiversity-related indicators, such as High-Nature-Value farmland and Natura 2000 areas, are critical for preserving ecosystems and ensuring the long-term viability of agricultural productivity. Economic factors, including cropping patterns and intensification/extensification, reflect resource efficiency and sustainability in agricultural systems. Together, these factors offer a balanced framework for advancing the Sustainable Development Goals (SDGs) in the Baltic region.

The Baltic countries face several unique challenges in their pursuit of agricultural sustainability. Intensive farming practices, such as excessive fertilizer use and monocropping, have led to soil degradation and pollution risks, as highlighted by Hou et al. (2020) [2]. Biodiversity loss remains a pressing issue, with farmland habitats threatened by land use changes and urbanization. Additionally, the impacts of climate change, including rising temperatures and altered precipitation patterns, pose significant risks to agricultural productivity and food security, as discussed by Pe'er et al. (2020) [43]. These challenges necessitate strategic interventions to promote sustainable practices and mitigate environmental impacts.

This study highlights Latvia's consistent sustainability performance across environmental, economic, and biodiversity indicators, suggesting its practices could serve as benchmarks for Lithuania and Estonia. Strategies such as crop rotation, efficient irrigation, and increased adoption of renewable energy were identified as critical for improving Estonia's rankings. Similarly, enhancing Natura 2000 areas and prioritizing biodiversity metrics like farmland bird populations are key for fostering resilience. Sensitivity analysis confirmed the robustness of these findings, indicating consistent rankings across diverse scenarios.

The relevance of these indicators is supported by the existing literature. For instance, Heyl et al. (2021) emphasize the importance of biodiversity indicators like High-Nature-Value farmland in preserving ecological integrity [36]. Hou et al. (2020) highlight the role of improved land use practices in mitigating soil degradation and reducing greenhouse gas emissions [2]. Additionally, Streimikis et al. (2024) demonstrate the potential of renewable energy to contribute to both agricultural and environmental sustainability. These studies validate the indicators used in this research, demonstrating their effectiveness in assessing and promoting sustainable land use practices [2].

Latvia emerged as the leader in overall sustainability, particularly excelling in biodiversity-related metrics such as farmland bird populations and areas under Natura 2000. These results indicate Latvia's strong commitment to preserving natural habitats and implementing conservation practices. However, Latvia showed weaknesses in water quality indicators, such as nitrate pollution and pesticide runoff, suggesting that its agricultural practices could benefit from stricter environmental controls and improved water management systems. These findings align with research by Heyl et al. (2021), which highlights biodiversity conservation as a cornerstone of sustainable land use [36].

Lithuania demonstrated balanced performance across most indicators, reflecting moderate strengths in energy efficiency and renewable energy adoption. These results indicate a commitment to sustainable energy transitions, which are essential for reducing greenhouse gas emissions. However, Lithuania underperformed in biodiversity metrics, such as farmland bird populations, pointing to opportunities for enhancing habitat conservation and integrating biodiversity-focused practices. This observation aligns with Streimikis et al. (2024), who emphasized the need for targeted biodiversity investments in Lithuania to achieve a more holistic sustainability profile [6].

Estonia, while excelling in organic farming and certain biodiversity metrics, ranked third overall due to weaknesses in pesticide use, water quality, and greenhouse gas emissions. These findings suggest that Estonia's agricultural practices may rely more heavily on chemical inputs, which negatively impact environmental sustainability. Improved regulatory frameworks and the adoption of eco-friendly farming practices are critical to addressing these challenges. The need for stricter controls on pesticide use has been similarly noted in studies by Hou et al. (2020) [2].

The results underscore the intrinsic connection between agri-environmental indicators and sustainable land use practices. Latvia's leadership in biodiversity conservation is reflected in its effective use of High-Nature-Value farmland, which contributes to habitat preservation and sustainable agricultural productivity. In contrast, Lithuania's balanced but moderate performance highlights the need for more targeted land use strategies, such as crop diversification and soil conservation. Estonia's challenges with pesticide use and water quality illustrate the environmental costs of intensive farming practices and emphasize the importance of adopting more sustainable approaches to land management. These findings align with the European Union's Common Agricultural Policy (CAP), which prioritizes sustainable land use as a key objective.

The study's findings are consistent with global and regional research on agricultural sustainability. For example, Pe'er et al. (2020) emphasized the role of biodiversity conservation in enhancing ecosystem resilience and agricultural productivity, as seen in Latvia's strong performance [43]. Similarly, Hou et al. (2020) highlighted the importance of renewable energy adoption and soil conservation practices in mitigating greenhouse gas emissions, which are areas of strength for Lithuania [2]. However, Estonia's challenges with pesticide use and water quality echo broader concerns about the environmental impacts of intensive agriculture, as noted by Streimikis et al. (2024) [6].

This research has significant implications for policymakers and stakeholders in the Baltic region. Policymakers can use these findings to design targeted interventions, such as increasing funding for environmental conservation, incentivizing organic farming, and enforcing stricter regulations on pesticide use. Stakeholder engagement is equally critical to ensure successful implementation, as collaboration among farmers, environmental organizations, and government agencies is essential for achieving sustainability goals. By addressing identified challenges and leveraging proposed measures, the Baltic countries can enhance their agri-environmental sustainability and contribute to global sustainability efforts.

In conclusion, this study provides valuable insights into the agri-environmental sustainability of Lithuania, Latvia, and Estonia. By ranking the countries based on multiple criteria, it offers a comprehensive understanding of their relative strengths and weaknesses. These findings serve as a foundation for developing targeted strategies to enhance sustainability, promote biodiversity, and ensure the resilience of agricultural systems in the Baltic region. Future research could expand on this work by incorporating additional indicators, exploring the social dimensions of sustainability, or conducting cross-regional comparisons to identify global best practices.

6. Conclusions

This study evaluates agri-environmental indicators to assess the sustainability of land use practices in the Baltic countries—Lithuania, Latvia, and Estonia—using the TOPSIS method and Eurostat data. By ranking these countries based on multiple sustainability

criteria, the study offers a comprehensive understanding of their performance in agri-environmental sustainability. The findings reveal that Latvia performs slightly better than Lithuania, with Estonia ranking third. These rankings provide insights into the strengths and areas for improvement in each country's approach to sustainable agriculture and land management.

The use of agri-environmental indicators, including biodiversity conservation, greenhouse gas (GHG) emissions, organic farming, and water management, highlights their critical role in evaluating sustainability. Biodiversity indicators, such as High-Nature-Value farmland and farmland bird populations, emerged as key metrics for ecological health, reflecting the importance of maintaining diverse and resilient ecosystems. Similarly, renewable energy production and reduced pesticide use directly influence environmental sustainability and agricultural resilience. By applying the Multi-Criteria Decision-Making (MCDM) methodology, this study integrates diverse quantitative and qualitative factors, providing a robust framework for assessing and ranking sustainability.

One of the key contributions of this research is its focus on the Baltic region, which faces unique historical, economic, and environmental challenges. The transition from centralized economies to market-oriented systems has significantly influenced land use patterns, leading to issues such as soil degradation, biodiversity loss, and climate-related vulnerabilities. The findings underscore the need for targeted strategies to address these challenges. For example, promoting organic farming, improving irrigation systems, and adopting renewable energy technologies can enhance agricultural resilience while mitigating environmental risks.

However, the analysis primarily reflects the current state of the indicators and does not directly assess whether specific practices are harmful or beneficial. To enhance the practical application of these findings, future research should analyze how changes in indicator values over time correspond to specific agricultural and environmental practices. This would provide a clearer understanding of the causal relationships between practices and sustainability outcomes.

The results of this study offer several actionable recommendations for policymakers and agricultural managers. Latvia, while demonstrating strong performance in biodiversity conservation and soil management, should focus on improving water quality and reducing nitrate pollution. Lithuania's moderate performance highlights opportunities to strengthen biodiversity initiatives, complementing its energy efficiency efforts. Estonia, ranking third, should prioritize addressing pesticide use and nitrate pollution while building on its strengths in organic farming and biodiversity conservation. These recommendations provide a roadmap for targeted interventions to address pressing sustainability challenges in the region.

Future research can build on this study by incorporating stakeholder perspectives, such as those of farmers, environmental organizations, and rural communities, to ensure that sustainability strategies are both practical and inclusive. The integration of advanced technologies, including precision agriculture, blockchain for supply chain transparency, and satellite-based monitoring, could further refine the evaluation and implementation of sustainable practices. Moreover, cross-regional studies comparing the Baltic countries with other regions would provide deeper insights into global best practices and innovative approaches to agricultural sustainability.

In conclusion, this research demonstrates the importance of agri-environmental indicators in evaluating and promoting sustainable land use practices. By bridging the gap between scientific analysis and practical application, it underscores the need for collaboration between researchers, policymakers, and practitioners to create resilient agricultural systems that balance environmental conservation with socio-economic development.

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