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Ranking Agricultural Competitiveness in Baltic Countries Using Multicriteria Decision Making (MCDM)

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Abstract

The competitiveness of agriculture is one of the critical factors in on-going sustainable development conversations, especially in the Baltic countries, which are agriculturally dependent even today. This paper analyzes the agricultural competitiveness of Lithuania, Latvia, and Estonia using a comprehensive matrix that encompasses economics, technology, trade, institutions, and new sustainability. This study employs durable decision-making approaches like FUCOM and TOPSIS, allowing for an exhaustive and systematic analysis of the competitiveness antecedents across these countries. Accordingly, the outcomes show the most radical disparities within the Baltic states. Lithuania was identified as the most competitive country due to its extremely low cost advantage, higher labor productivity, and quality policy support. Estonia is second, due to evidence of technological competencies and successful market diversification. Latvia is left behind because of productivity issues and inadequate market diversification. These results underscore that interventions, such as spending on technology and infrastructure, market liberalization, and structural improvements, need to be crafted to meet country-level deficiencies. This study also highlights sustainability and climate change as factors that have influenced agricultural competitiveness as global markets pay more attention to issues of sustainability. The integration of MCDM methodologies guarantees an effective and credible evaluation process, which would provide the possibility of the replication of similar studies in other regions and fields. In filling these research gaps, this work can help policymakers and stakeholders to plan and propel the Baltic region towards a better, stronger, and more sustainable farming and agriculture sector.

Keywords: *Agricultural Competitiveness, Baltic Countries, Multicriteria Decision Making (MCDM), Sustainability in Agriculture, FUCOM, TOPSIS*

JEL Classification: Q10, Q18, O13, C44, C61, F14, L11

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1 INTRODUCTION: This study employs an analytical framework to examine agriculture, considered one of the most crucial social activities, functioning as an essential foundation for economic, food, and nutritional security, and acting as a cornerstone for livelihoods in nearly all communities globally. Lithuania, Latvia, and Estonia are three Baltic countries located in the northeast portion of Europe, which contributes to the distinctive character of their positions within the area of agriculture as a result of their historical evolution and being a part of the European Union. Since these states entered the European Union, they have undergone significant transformations, received financial assistance, and implemented structural reforms, while also adhering to new regional and international regulations (Hartmann et al., 2021).

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Although advancements in the agricultural sectors of these three Baltic States are apparent, numerous challenges impacting the competitiveness of the agricultural industry continue to be debated at both regional and international levels (Balezentis & Sapolaite, 2022).

Competitiveness in agriculture is best characterized as a multifaceted phenomenon. It has been operationally defined as the capacity of a country or region to generate income from the production and marketing of agricultural produce in domestic and export markets and at the same time improve on the current position (Mizik, 2021). Thus, competitiveness for Baltic countries is constructed through economic, technological, and institutional processes. These are cost of production, labor productivity, export performance, and the extent of adoption of superior production technologies (Karman & Savanevičienė, 2020). However, the region also has challenges, including the small market available that the AEC can serve, reliance on E.U. agricultural subsidies, as well as the increased effects of climate change. While the global agricultural markets are soon to become more competitive, awareness and enhancement of competitiveness can be critical to the future sustenance of the Baltic countries' admittedly high economic performance, which can help achieve a range of objectives and goals within the European Union (Kristiansen & Earle, 2022).

The imperative to focus on the competitiveness of agriculture stems from the sector's significant importance to these nations (Matkovski et al., 2022). For example, in Lithuania, agriculture remains a significant gross domestic product provider as well as a source of employment and rural growth. However, issues concerning the production cost, instability in price of the commodities to be produced, and problems of market access have dampened the long-term view of the sector. Latvia and Estonia share many of these challenges, but the intensity may vary across regions in structures and policies in agriculture. Solving these problems presupposes the understanding of the determinants of competitiveness and the bifurcated process of selecting priorities for action (Miskinis et al., 2023).

One of the major research gaps in the current literature is the absence of individual studies that provide an overall evaluation of the agricultural competitiveness in the context of the Baltic countries (Štreimikienė et al., 2024a). Most of the prior work has been conducted in a partial view based on productivity, sustainability, and technological integration. Despite the fact that these studies can give useful information, researchers tend to pay inadequate attention to the factor of competitiveness in its more complex sense that unifies the variables like economic outcomes, exports, imports, and institutional environment. However, there are more or less no comparative studies comparing the Baltic states, although they face similar problems and opportunities within the region. This gap points to the lack of a study that assesses competitiveness comprehensively yet uses sound research instruments to rank and prioritize the indicators for improvement (Ali & Manthar, 2026; Ostojic et al., 2024).

The multicriteria decision making (MCDM) approach provides the best way of filling this gap in research. In particular, the MCDM methods enable us to compare the values of multiple criteria that often contradict one another; this characteristic puts these methods into focus for analyzing complex systems such as agriculture (Taherdoost & Madanchian, 2023). Therefore, using the MCDM techniques, the goal of this study is to offer a detailed framework for Lithuanian, Latvian, and Estonian agricultural competitiveness. Benchmark indicators comprising the general cost, labor productivity, export revenue, and technology integration in agriculture will be used to compare the competitiveness of agriculture in the region. In addition

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to the effectiveness of the assessment, this approach will offer useful information to policymakers, industries, and farmers (Dashti & Rostamzadeh, 2026; Zia et al., 2022).

The problems of the agricultural sector problems in Baltic countries are complex. High production costs, including those attributed to input factors such as fertilizer and energy, have had an impact on profitability, and therefore cost control as a competitive advantage has emerged as being central to competitiveness across the country. However, the factor that might be seen as an advantage, the larger prominence of E.U. markets in the region, implies policy shifts and trade volatility. Technology amplifies these problems, as most of the farming operations cannot afford innovations such as precision farming and digitization because of steep start-up costs and inadequate skills. Last but not least, the volatile experience of climate change remains an implied factor that could affect yields and economic stability due to shocks in weather patterns. Such challenges highlight the need for and importance of conducting a more structured and focal analysis of competitiveness to support the decision-making process and to design relevant intervention policies.

Using MCDM techniques, the principal objective of this study is to assess and compare the level of competitiveness of the agriculture of Lithuania and other Baltic countries. The potential object of investigation will include such areas of analysis as the identification of the primary factors of competitiveness, the evaluation of current agricultural outcomes in the researched region, and the determination of strategic improvements aimed at improving this sphere's economic performance. As a result, the study will examine economic efficiency and trade performance, technological advancement, and institutional support. Comparing these indicators, the study will analyze current specificities of the Baltic countries and suggest potential niches for cooperation and development.

This study fills a gap in the literature by assessing a critical research problem while offering practical solutions. Several previous works have analyzed various factors related to agricultural performance, but none have examined competitiveness as a specific, complex concept in the Baltic area. In addition, there is also a lack of the MCDM methods applied in this field, although this can offer quite detailed and decision-oriented analysis. Consequently, this study contributes to methodological developments and applications of MCDM by illustrating a case of ranked assessment of such a complex factor as competitive advantage in the agricultural industry.

Finally, agriculture in the Baltic states is currently at a crossroads, or to be more precise, it is going through that stage when it acts on one hand and experiences certain threats, and on the other hand, it opens certain opportunities on the international level. Improving competitiveness is crucial for the economic viability of the sector as well as for its role in the functioning of the regional and E.U. economies. It is against this backdrop that this study offers a systematic and detailed understanding of the agricultural competitiveness of Lithuania, Latvia, and Estonia. Hence, by the use of MCDM techniques, this studyshall provide usable findings and generate implementable recommendations that note the intricate findings and warrant protection, thus opening a new and constructive discussion on how the Bretton Woods institutions can devise smarter lending strategies and contribute to creating a more competitive and sustainable agricultural sector in the Baltic area.

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2 THEORETICAL BACKGROUND:

Food production has alwaysplayed a central role in man's development, not only contributing to economic growth and the stability of rural areas but also the provision of foods (Maja & Ayano, 2021). In the three Baltic countries of Lithuania, Latvia, and Estonia, agriculture remains closely connected with economic stability and food security. These countries have experienced major changes in agricultural systems policies and practices over the years, largely due to de-modernization campaigns, membership in the European Union, and the increasing influence of globalization. However, the sector continues to experience the following challenges even with the recent innovations: increased production costs, changing market forces, and increasing effects of climate change. It is high time that these issues were resolved to maintain agricultural competitiveness and further the sector's positive impact on economies of the region (Ngoc et al., 2021).

Agricultural competitiveness is defined as the extent to which a country or a region is effective in the production of agricultural commodities and in the generation of profits from the production of these goods both within and outside the country (Campi et al., 2021; Redkinaitė, 2026). This does not only capture output and efficiency; it also gets input from market factors, technological prospects, exports, and the institutional framework. For the Baltic region, competitiveness may be explained by factors of endowment: the quality of soil, favorable climate conditions, and external factors like access to markets, subsidies from the European Union, market regulations, and appropriate use of high technologies in farming. These keep defining the agricultural framework and its capability to mitigate various challenges and exploit enhanced opportunities in the increasing competition globally (Streimikis & Baležentis, 2020).

A key competitive factor is cost efficiency, the ability to attain the lowest possible costs during the production process to attain the highest possible result. Increased costs of energy, fertilizers, and labor have posed a great challenge to Baltic farmers, more so the small-scale family farming businesses than the larger companies (Kurlavičius et al., 2024). Optimization of costs requires specific actions like increasing awareness about better resource use and application of smart farming techniques, efficient procurement and supply, etc. Benchmarking studies between Lithuania, Latvia, and Estonia can uncover specific instances that require changes and which would help stakeholders to allocate their resources well and make proper adjustments (Streimikiene et al., 2023).

Labor productivity is another factor that defines the competitiveness of an agricultural sector. When measured as output per worker or level of labor input, the Baltic countries' productivity rates are lower than in developed E.U. countries (Štreimikienė et al., 2024a). This productivity gap can be attributed, among other things, to inadequate mechanization and low technology acquisition. To fill this gap, more than just mere mechanization of the various processes of agricultural production is required: investments in education and training schemes, physical facilities, and properties, as well as the enhancement of appropriate technologies to assist farmers to do it better (Agyei-Holmes, 2020).

Technology now occupies a central point and serves as a way to extend modification in contemporary agriculture value. Technologies such as precision farming, technological applications, and biotechnology help farmers to efficiently use resources and produce more, and at lower costs (Khan et al., 2021). TVET in the Baltic countries has an additional issue: the

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differentiated implementation of these technologies. Huge farms can afford more expensive and hi-tech solutions, while small and medium-sized farms cannot afford expensive high-tech apparatuses and do not have the expertise needed to implement such solutions. It is going to take considerable efforts, inclusive of PPP, governmental-supported innovation, and subsidies to spread innovation across the population (Xu, 2023).

Among other critical determinants, trade performance also plays a significant role in determining agricultural competitiveness. Market access is particularly important for small countries such as Lithuania (Jarosz-Angowska et al., 2022). Although Lithuania has improved its performance in exporting agricultural products, especially cereals, dairy products and meat, the country is exposed to some geopolitical and economic shocks due to its limited export destinations. To strengthen the competitiveness of developing countries in the region in the international market, there is a need to increase the range of export products, diversify export markets and diversify manufactured export products, which include processed foods and organic products (Jongwanich, 2020).

Policies, subsidies, and regulatory measures belong to the institutional environment and have a crucial effect on the agricultural performance. CAP subsidies have played a crucial role in the process of agriculture modernization in the European Union; nevertheless, certain critical dependency on the subsidies was identified as a potential issue (Heyl et al., 2022). The pertinent reforms that need to be implemented involve the focus on developing institutional capacity, improving the regulatory quality, and encouraging initiatives so as to increase the competitiveness and relative autonomy of the agricultural sector (Lintner & Elsen, 2020).

Climate variability is another complicating factor in agricultural competitiveness. Changing rainfall patterns, high temperatures, and heightened incidence of storms and other extreme conditions present considerable risks to crop yields and farming incomes (Alrteimei et al., 2022). Using climate-smart practices like switching to drought-resistant crops, improving irrigation, and mostly improving the soil is crucial for the improvement of productivity and resourcefulness. Bearing in mind that climate risks are long-term, integration of climate adaptation measures into the competitiveness agenda in the Baltic Sea region guarantees the sustainability of the agricultural sector (Alonso Soto & Stasiškienė, 2024).

However, agricultural competitiveness has received limited scholarly attention in the Baltic literature. Some previous works analyze global competitiveness from one or two perspectives, for instance, from the perspectives of productivity or sustenance or from the perspective of trade, but do not capture a comprehensive picture from a competitiveness viewpoint (Jakob et al., 2020). Furthermore, more sophisticated decision-supporting tools and methodologies, which include the multi-criteria decision-making (MCDM) techniques, remain unused in this context. Earlier MCDM methods such as FUCOM and TOPSIS offer solid ground for assessing competitiveness indicators performance and ranking (Hezam et al., 2022). FUCOM maintains a relative consistency in the weighting of criteria, and TOPSIS ranks the alternatives closer to the ideal solution. Altogether, the methods presented are multimethod and provide an extensive and clear deterministic approach to the assessment of agricultural competitiveness that is the key scope of this study (Ocampo, 2022).

Literature from other parts of the world shows the applicability of MCDM techniques in agriculture-related research. For example, Štreimikienė et al. (2024) used TOPSIS in analyzing

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the trade competitiveness of agricultural exports in E.U. countries in the context of factors such as trade balance, market share of product, and costs of production (Štreimikienė et al., 2024a).

To eliminate these gaps, this study proposes to use FUCOM and TOPSIS to assess and compare the competitiveness of agriculture in the Baltic states. It examines competitiveness through economic, technological, trade, and institutional lenses while trending the indicators to a full suite. Also, this study adds sustainability and climate resistance to competitiveness as important qualities, making the results actionable for the region but also globally useful. The findings will not only contribute to the existing literature but also provide policy implications and suggestions for policymakers, related industries, and farmers. This approach shifts competitiveness from an analytical concept to a process model that informs the sustainable growth of the agriculture sector. Table 1 shows the indicators obtained from Eurostat and FAO.

Table 1 Indicators obtained from Eurostat and FAO.
Source: own research

Code	Indicator	Explanation	Source
A1	Cost Efficiency	Measures the ratio of input costs (e.g., labor, materials) to agricultural output.	Eurostat, FAO
A2	Labor Productivity	Assesses agricultural output per unit of labor input (e.g., per worker or labor hour).	Eurostat, National Stats
A3	Export Performance	Evaluates the value and volume of agricultural goods exported to international markets.	Eurostat, Trade Reports
A4	Market Diversification	Analyzes the diversity of export destinations and product categories in the agricultural sector.	Eurostat, WTO
A5	Innovation Adoption	Examines the level of adoption of modern farming technologies, such as precision agriculture.	Research Studies, FAO
A6	Policy Support	Evaluates the effectiveness of governmental and EU policies, including subsidies, in agriculture.	CAP Reports, Eurostat

3 RESEARCH OBJECTIVE, METHODOLOGY AND DATA:

The objective of this study is to assess and rank the agricultural competitiveness of Lithuania, Latvia, and Estonia using an integrated multicriteria decision-making framework. The full consistency method (FUCOM) was employed to determine the relative importance of the evaluation criteria, while the technique for order preference by similarity to ideal solution (TOPSIS) was used to rank the three countries according to their overall performance. The combination of these methods enables a transparent and systematic assessment in which expert-based criterion weights are integrated with country-level performance data.

The evaluation criteria were identified through a review of the literature on agricultural competitiveness, agricultural productivity, trade performance, technological development, and institutional support. The preliminary set of indicators was subsequently examined through expert consultation. Based on this process, six criteria were selected: cost efficiency, labor productivity, export performance, market diversification, innovation adoption, and policy support. These criteria represent the main economic, technological, trade-related, and institutional dimensions influencing agricultural competitiveness in the Baltic region.

An expert survey was conducted to validate the selected criteria and determine their relative importance. A total of 20 experts participated in the study. The expert panel consisted of

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policymakers from agricultural ministries, academic researchers, agricultural and financial economists, and practitioners involved in the agricultural sectors of Lithuania, Latvia, and Estonia. The participants were based in the three Baltic countries and possessed at least five years of professional or academic experience in agricultural economics, agricultural policy, rural development, agricultural management, or related fields.

A purposive sampling strategy was used to recruit experts with demonstrated knowledge of agricultural competitiveness in the Baltic region. Potential participants were identified based on their professional positions in governmental institutions, universities, research institutes, and agricultural organizations. Individual invitations were sent by email. The eligibility criteria included relevant professional or academic expertise, at least five years of experience in an agriculture-related field, familiarity with the agricultural sectors of the Baltic countries, and willingness to participate in the study.

The survey instrument consisted of a structured pairwise-comparison questionnaire developed in accordance with the standard FUCOM procedure. Experts first ranked the six evaluation criteria from the most important to the least important according to their professional judgment. They then compared each pair of adjacent criteria by expressing how many times the higher-ranked criterion was more important than the next-ranked criterion using ratio-based judgments. The comparative priority judgments obtained from the 20 experts were subsequently aggregated using the geometric mean to generate a single representative set of comparative priority ratios for the FUCOM analysis. Equal weights were assigned to all experts during the aggregation process. The resulting aggregated comparative priority ratios constituted the input for the FUCOM optimization model to derive the final criterion weights presented in Table 2. Before aggregation, all completed questionnaires were reviewed for completeness and logical consistency. Since all questionnaires satisfied the predefined eligibility and quality requirements, no expert responses were excluded from the analysis. To ensure consistency in the evaluation process, the questionnaire included clear instructions and definitions of each criterion. Participation in the expert survey was voluntary. Before completing the questionnaire, all participants were informed of the purpose of the study and the intended use of the collected information. Informed consent was obtained from all participants prior to their participation. The survey collected only professional opinions related to agricultural competitiveness and did not involve personal, sensitive, or confidential information. Therefore, according to the institutional regulations applicable to this study, formal ethical approval was not required.

FUCOM was selected because it derives criterion weights while minimizing deviations from full consistency in the experts' comparative judgments. Compared with methods requiring a larger number of pairwise comparisons, FUCOM reduces the elicitation burden and enables the derivation of consistent and transparent criterion weights. The final weights obtained through the FUCOM optimization model were normalized so that their sum equaled one and were subsequently incorporated into the TOPSIS analysis.

Country-level quantitative data for the selected criteria were obtained from established secondary sources, including EUROSTAT, national statistical institutions, the food and agriculture organization, trade reports, and agricultural policy databases. The collected data covered the agricultural performance of Lithuania, Latvia, and Estonia in relation to cost efficiency, labor productivity, export performance, market diversification, innovation adoption,

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and policy support. The use of comparable secondary data enabled the construction of the country's decision matrix used in the TOPSIS analysis.

TOPSIS was applied to rank the three countries according to their proximity to the positive-ideal solution and their distance from the negative-ideal solution. The positive-ideal solution represents the best observed performance across the selected criteria, whereas the negative-ideal solution represents the weakest observed performance. The country data were normalized, multiplied by the FUCOM-derived weights, and used to calculate the distances from both ideal solutions. A relative closeness coefficient was then calculated for each country, with a higher coefficient indicating a stronger overall level of agricultural competitiveness.

The methodological framework therefore integrates expert judgment with quantitative country-level data. FUCOM provides consistent weights for the selected competitiveness criteria, while TOPSIS produces a comparative ranking of Lithuania, Latvia, and Estonia. This combined approach supports the identification of country-specific strengths, weaknesses, and policy priorities within the agricultural sectors of the Baltic states.

FUCOM Method

FUCOM is a criteria weighting method for determining importance weights of criteria introduced by Pamučar et al. (2018). It utilizes a three-steps process: Step 1: rank criteria by importance: it requires the decision maker (or makers) to rank the criteria of the decision problem from most to least important. This ranked order offers a rough estimate of the weight coefficients, depicted in equation (1), and indicates the order of relative importance of the criteria.

$$C_{j(1)} > C_{j(2)} > \cdots > C_{j(k)} \qquad (1)$$

Step 2: determining the interrelation of the ranked criteria priorities: the relationship of the rankings proposed by the decision maker(s) within step 1 is assessed (equation (2)).

$$\Phi = \varphi_{1/2} > \varphi_{2/3} > \cdots > \varphi_{k/(k+1)} \qquad (2)$$

Here, $\varphi_{k/(k+1)}$ represents the relative importance of criterion $C_{j(k)}$ over $C_{j(k+1)}$.

Step 3: establishing the importance of the criteria: the final values of the weight coefficients of the criteria $(W_1, W_2, \ldots, W_n)^T$ are calculated. In order to calculate these weights, the following two conditions must be accomplished:

Condition 1. the ratio of the weight coefficients is equal to the value of the relative importance of the criteria (Equation 3).

$$\frac{W_k}{W_{k+1}} = \varphi_{k/(k+1)} \qquad (3)$$

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Condition 2: the final value of the weight coefficients must be in the order of mathematical transitivity.

Then

$\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Since $\frac{W_k}{W_{k+1}} = \varphi_{k/(k+1)}$ and $\varphi_{(k+1)/(k+2)} = \frac{W_{k+1}}{W_{k+2}}$, that $\frac{W_k}{W_{k+1}} \otimes \frac{W_{k+1}}{W_{k+2}} = \frac{W_k}{W_{k+2}}$ is obtained. Thus, equation 4 must be satisfied for the final values of the coefficients of the criteria weights.

$$\frac{W_k}{W_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \quad (4)$$

Satisfying full consistency requires that the conditions shown in equations 3 and 4 are met. The existence of these equations means that the consistency condition is fulfilled. That is, the deviation from full consistency (DFC(χ)) is minimal. DFC is $\chi = 0$. The final importance of the criteria is calculated by solving the linear programming model shown in equation 5.

Min χ

$$\left| \frac{W_{j(k)}}{W_{j(k+1)}} - \varphi_{\frac{k}{k+1}} \right| \leq \chi, \forall j$$

$$\left| \frac{W_{j(k)}}{W_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \leq \chi, \forall j$$

$$\sum_{j=1}^{n} w_i = 1, \forall j$$

$$w_j \geq 0, \forall j \quad (5)$$

By solving equation 5, the final importance weights $(W_1, W_2, \ldots, W_n)^T$ and DFC value of the criteria are calculated.

TOPSIS Method

The TOPSIS method is fundamentally predicated on the idea that the best solution has the shortest distance from the positive-ideal solution, and longest distance to negative-ideal one (Çelikbilek & Tüysüz, 2020). Alternatives were ordered by an overall ranking index computed on the basis of distances from ideal solutions.

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Step 1: Build the Decision Matrix

The TOPSIS procedure begins with the formulation of the initial decision matrix, which represents the performance of each alternative with respect to the selected evaluation criteria. The decision matrix $X = [x_{ij}]_{n\times m}$ is expressed as follows:

$$X = [x_{ij}]_{n\times m} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \quad (6)$$

where x_{ij} denotes the performance score of alternative A_i with respect to criterion C_j, n represents the number of alternatives, and m indicates the number of criteria.

Step 2: Normalize the Decision Matrix

Since the evaluation criteria may have different measurement units and scales, the original decision matrix is transformed into a dimensionless normalized matrix. The vector normalization approach is applied as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \quad (7)$$

where r_{ij} represents the normalized performance value of alternative A_i under criterion C_j. This transformation ensures comparability among all criteria before further calculations.

Step 3: Build the Weighted Normalized Decision Matrix

To incorporate the relative importance of each criterion, the normalized matrix is multiplied by the corresponding criterion weights. The weighted normalized value is calculated as

$$v_{ij} = w_j r_{ij};\ i = 1,2,\dots,n;\ j = 1,2,\dots,m$$

where w_j is the weight assigned to criterion C_j, and v_{ij} indicates the weighted normalized performance of alternative A_i with respect to criterion C_j.

Step 4: Determine the Positive Ideal and Negative Ideal Solutions

The next stage involves determining the ideal best and ideal worst solutions. The positive ideal solution A^+ represents the most desirable performance values across all criteria, whereas the negative ideal solution A^- represents the least desirable values:

$$A^+ = [v_1^+, v_2^+, .., .. v_m^+]$$
$$A^- = [v_1^-, v_2^-, .., .. v_m^-]$$

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The components of these solutions are determined according to the nature of each criterion:

$$v_j^+ = \begin{cases} \max(v_{ij}), & \text{if } C_j \text{ is a benefit criterion} \\ \min(v_{ij}), & \text{if } C_j \text{ is a cost criterion} \end{cases}$$

$$v_j^- = \begin{cases} \min(v_{ij}), & \text{if } C_j \text{ is a benefit criterion} \\ \max(v_{ij}), & \text{if } C_j \text{ is a cost criterion} \end{cases}$$

where benefit criteria are those for which higher values indicate better performance, while cost criteria represent factors where lower values are preferred.

Step 5: Calculate the Separation Measures

The degree of separation between each alternative and the positive and negative ideal solutions is calculated using the Euclidean distance method:

$$S_i^+ = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^+)^2} \quad (8)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^-)^2} \quad (9)$$

where S_i^+ and S_i^- indicate the distances of alternative A_i from the positive and negative ideal solutions, respectively.

Step 6: Calculate the Relative Closeness to the Ideal Solution

The relative preference of each alternative is obtained by calculating its closeness coefficient to the ideal solution:

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-} \quad (10)$$

where C_i^* represents the relative closeness value of alternative A_i. A larger value of C_i^* indicates that the alternative is positioned closer to the positive ideal solution and farther from the negative ideal solution.

Step 7: Rank the Alternatives

In the final stage, alternatives are ranked according to their calculated closeness coefficients (C_i^*). Alternatives with higher C_i^* values receive better rankings because they demonstrate greater similarity to the positive ideal solution and superior overall performance compared with other alternatives.

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4 RESULTS AND DISCUSSION:

The analysis of agricultural competitiveness among Lithuania, Latvia, and Estonia was conducted using a structured multi-criteria decision-making (MCDM) framework. The FUCOM method was employed to determine the relative importance of key evaluation criteria, ensuring logical consistency in weighting. These weights were then applied in the TOPSIS method to rank the countries based on their performance across selected indicators, such as cost efficiency, labor productivity, and market diversification. The combined approach ensured a robust and systematic evaluation of competitiveness across the Baltic states.

FUCOM Results

The FUCOM was employed to determine the weights of the criteria used in evaluating agricultural competitiveness. The method ensures logical consistency in pairwise comparisons and provides robust weights. The steps followed and the results obtained are detailed below.

Define Criteria

The criteria selected for evaluating agricultural competitiveness in this study are as follows: cost efficiency, labor productivity, export performance, market diversification, innovation adoption, and policy support.

Perform Pairwise Comparisons

Pairwise comparisons between criteria were conducted to assess their relative importance. The relative importance ratios (r_{ij}) were obtained from the judgments of the 20 experts who participated in the FUCOM survey. Following the FUCOM methodology, the experts compared the relative importance of adjacent criteria using pairwise comparisons. The individual judgments were consolidated into a single representative relative importance ratio for each comparison. These comparative priority ratios were then used as the input to the FUCOM optimization model to derive the final criterion weights while satisfying the full consistency condition. Table 2 presents the resulting pairwise comparison ratios.

Table 2: Pairwise Comparison Ratios
Source: own research

Criteria Pair (i, j)	Relative Importance Ratio (r_ij)
Cost Efficiency vs Labor Productivity	1.25
Cost Efficiency vs Export Performance	1.67
Labor Productivity vs Export Performance	1.33
Export Performance vs Market Diversification	1.00
Market Diversification vs Innovation Adoption	1.50
Policy Support vs Market Diversification	0.67

The relative importance ratios presented in table 2 represent the comparative priorities between adjacent criteria and constitute the input parameters for the subsequent consistency verification and weight derivation process.

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Verify Consistency

The consistency of pairwise comparisons was verified using the consistency condition $r_{ij} \times r_{jk} = r_{ik}$. Adjustments were made, where necessary, to ensure logical consistency across all pairwise comparisons.

Derivation of Criterion Weights

After verifying consistency, the comparative priority ratios presented in table 2 were used as the input to the FUCOM optimization model (equation 5). The optimization model determines the criterion weights by minimizing the deviation from full consistency (DFC). The obtained weights were subsequently normalized so that their sum equals one before being used in the TOPSIS analysis. Table 3 presents the final normalized weights of the evaluation criteria.

Table 3: Final Weights
Source: own research

Criterion	Weight
Cost Efficiency	0.25
Labor Productivity	0.20
Export Performance	0.15
Market Diversification	0.15
Innovation Adoption	0.10
Policy Support	0.15

The FUCOM method provided consistent and reliable weights for the selected criteria. These weights serve as the basis for evaluating and ranking agricultural competitiveness using the TOPSIS method in the next phase of the analysis.

TOPSIS Results

The TOPSIS was applied to rank the countries based on their performance across the selected criteria. The method evaluates each country based on its distance to an ideal solution (the best performance) and an anti-ideal solution (the worst performance).

Construct the Decision Matrix

The original data for the selected criteria and countries was organized into a decision matrix. The rows represent the countries, and the columns represent the criteria. Table 4 shows the decision matrix.

Table 4: Decision Matrix (Original Data)
Source: own research

Country	Cost Efficiency	Labor Productivity	Export Performance	Market Diversification	Innovation Adoption	Policy Support
Lithuania	0.85	0.78	0.9	0.76	0.65	0.88
Latvia	0.75	0.7	0.65	0.68	0.62	0.72
Estonia	0.8	0.82	0.72	0.81	0.7	0.75

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Normalize the Decision Matrix

The decision matrix was normalized to ensure comparability across criteria. The normalized value for each criterion was calculated using the formula: r_ij = x_ij / sqrt(sum(x_ij^2)). Table 5 shows the normalized decision matrix.

Table 5: Normalized Decision Matrix
Source: own research

Cost Efficiency	Labor Productivity	Export Performance	Market Diversification	Innovation Adoption	Policy Support	Country
0.612	0.586	0.680	0.583	0.570	0.646	Lithuania
0.540	0.526	0.491	0.522	0.544	0.528	Latvia
0.576	0.616	0.544	0.621	0.614	0.550	Estonia

Apply Weights to Normalized Data

The normalized data was multiplied by the weights derived using the FUCOM method to create the weighted normalized decision matrix. This step ensures that each criterion contributes to the analysis based on its relative importance. Table 6 shows the weighted normalized decision matrix.

Table 6: Weighted Normalized Decision Matrix
Source: own research

Cost Efficiency	Labor Productivity	Export Performance	Market Diversification	Innovation Adoption	Policy Support	Country
0.153	0.117	0.102	0.087	0.057	0.096	Lithuania
0.135	0.105	0.073	0.078	0.054	0.079	Latvia
0.144	0.123	0.081	0.093	0.06	0.082	Estonia

Determine Ideal and Anti-Ideal Solutions

The ideal solution represents the best possible performance for each criterion, while the anti-ideal solution represents the worst performance. These were determined from the weighted normalized matrix.

Calculation of Distances from Ideal and Anti-Ideal Solutions

The Euclidean distances between each alternative and the positive ideal solution (A^+) as well as the negative ideal solution (A^-) were calculated using the following equations:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - A_j^+)^2}$$

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$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - A_j^-)^2}$$

where D_i^+ and D_i^- represent the distances of alternative i from the ideal and anti-ideal solutions, respectively. A smaller D_i^+ value indicates greater proximity to the optimal solution, whereas a larger D_i^- value reflects greater separation from the worst-case solution.

Calculation of TOPSIS Scores and Ranking of Alternatives

The relative closeness coefficient (TOPSIS score) for each alternative was subsequently determined using the following equation:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-}$$

The calculated C_i values range between 0 and 1, where higher values indicate that an alternative is closer to the positive ideal solution and performs better compared with other alternatives. Based on these scores, all alternatives were ranked in descending order of performance. The resulting TOPSIS scores and corresponding rankings are presented in table 7.

Table 7: TOPSIS Scores and Rankings
Source: own research

Country	Cost Efficiency	Labor Productivity	Export Performance	Market Diversification	Innovation Adoption	Policy Support	TOPSIS Score	Rank
Lithuania	0.85	0.78	0.9	0.76	0.65	0.88	0.813	1
Latvia	0.75	0.7	0.65	0.68	0.62	0.72	0.0	3
Estonia	0.8	0.82	0.72	0.81	0.7	0.75	0.508	2

The TOPSIS method ranked the alternatives according to their overall performance across the selected evaluation criteria. Lithuania achieved the highest TOPSIS score (0.813), followed by Estonia (0.509), while Latvia ranked third with a score of 0.000. Latvia obtained a relative closeness coefficient of zero because it recorded the lowest performance values among the three evaluated countries across all six assessment criteria. Consequently, Latvia coincided with the negative-ideal solution in the TOPSIS analysis, resulting in a zero distance from the negative-ideal solution and, therefore, a relative closeness coefficient of zero. This result should be interpreted as reflecting Latvia's relative position within the selected three-country comparison and the evaluated criteria rather than indicating an absolute absence of agricultural competitiveness. Instead, it demonstrates that Latvia exhibited the weakest overall performance among the evaluated alternatives under the adopted assessment framework. These findings provide valuable insights for policymakers and stakeholders seeking to identify country-specific priorities for improving agricultural competitiveness in the Baltic region.

The results of this study present a comprehensive analysis of agricultural competitiveness in Lithuania, Latvia, and Estonia using the FUCOM and TOPSIS methodologies. By determining

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the relative importance of key indicators such as cost efficiency, labor productivity, and export performance, FUCOM provided robust and consistent weights that informed the subsequent ranking process. Applying these weights, the TOPSIS method identified Lithuania as the most competitive country, followed by Estonia and Latvia. This structured evaluation not only highlights the disparities in agricultural performance across the Baltic states but also provides actionable insights for targeted policy interventions to strengthen regional agricultural competitiveness.

Sensitivity Analysis Results

Sensitivity analysis was conducted to assess the robustness of the TOPSIS results. The weights of key criteria were adjusted incrementally by ±10%, and the impact on the rankings of the alternatives (Lithuania, Latvia, and Estonia) was evaluated. This analysis helps to ensure that the rankings are not overly dependent on specific weight assignments, providing greater confidence in the results. Table 8 shows the sensitivity analysis.

Table 8 Results of Sensitivity Analysis.
Source: own research

Adjusted Criterion	Adjustment	Lithuania Score	Latvia Score	Estonia Score	Lithuania Rank	Latvia Rank	Estonia Rank
Cost Efficiency	Decrease	0.810	0.0	0.509	1	3	2
Cost Efficiency	Increase	0.816	0.0	0.508	1	3	2
Labor Productivity	Decrease	0.817	0.0	0.498	1	3	2
Labor Productivity	Increase	0.808	0.0	0.519	1	3	2
Export Performance	Decrease	0.805	0.0	0.521	1	3	2
Export Performance	Increase	0.820	0.0	0.496	1	3	2
Market Diversification	Decrease	0.817	0.0	0.501	1	3	2
Market Diversification	Increase	0.808	0.0	0.516	1	3	2
Innovation Adoption	Decrease	0.816	0.0	0.507	1	3	2
Innovation Adoption	Increase	0.809	0.0	0.510	1	3	2
Policy Support	Decrease	0.810	0.0	0.515	1	3	2
Policy Support	Increase	0.815	0.0	0.501	1	3	2

The sensitivity analysis shows that the overall rankings of the countries remain stable despite adjustments to the weights of the criteria. Lithuania consistently ranks as the most competitive, followed by Estonia and Latvia. These results demonstrate the robustness of the TOPSIS analysis and the reliability of the FUCOM-derived weights.

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Discussion

This study examined the agricultural competitiveness of Lithuania, Latvia, and Estonia using FUCOM and TOPSIS methodologies, offering a structured and replicable framework for evaluating regional disparities. The findings highlight significant variations across the three countries, each demonstrating unique strengths and weaknesses influenced by economic, technological, and institutional factors.

Lithuania emerged as the most competitive country, supported by its superior cost efficiency, labor productivity, and robust policy framework. This aligns with findings from Balezentis et al. (2023), who identified productivity improvements and cost advantages as critical drivers of Lithuania's agricultural sector performance (Baležentis et al., 2023). By leveraging EU subsidies effectively, Lithuania has modernized its agricultural infrastructure, optimizing input costs and enhancing labor efficiency. However, reliance on a limited number of export markets presents a significant risk to long-term sustainability. Expanding export destinations and focusing on high value-added products, such as processed and organic agricultural goods, would mitigate geopolitical and economic vulnerabilities. Additionally, integrating renewable energy and climate-smart practices such as advanced irrigation systems and sustainable soil management will align Lithuania with global sustainability goals, as emphasized in recent studies on low-carbon agricultural transitions (Bathaei & Streimikiene, 2023).

Estonia ranked second in the competitiveness assessment, showcasing strengths in technological adoption and market diversification. Significant investments in precision agriculture and digital technologies have strengthened Estonia's productivity, positioning the country as a technological leader within the region. This observation is consistent with the findings of Himma-Kadakas and Kõuts-Klemm (2023), who highlight Estonia's progress in digital transformation and its positive impact on the agricultural sector. However, challenges remain in cost efficiency and export performance. Addressing these issues will require targeted investments in supply chain infrastructure, particularly in transportation and logistics, to optimize production costs. Promoting high value-added agricultural exports, such as processed foods, will further improve Estonia's competitiveness. Incorporating climate-smart agricultural practices, including drought-resistant crops and enhanced soil management, will ensure resilience against climate variability and align with global sustainability standards, as noted by Okeke (2021).

Latvia, in contrast, ranked lowest due to systemic inefficiencies, including low labor productivity, limited technological adoption, and poor product diversification. While E.U. subsidies provide financial support, structural challenges hinder Latvia's agricultural performance, echoing observations by Julie et al. (2022) on modernization gaps in European agriculture (Ingram et al., 2022). Addressing these challenges requires comprehensive reforms to improve productivity and market access. Investments in rural infrastructure, such as transportation networks and storage facilities, are critical to reducing production costs and enhancing supply chain efficiency. Further, promoting the adoption of advanced technologies through targeted financial incentives and training programs would enable small and medium-sized farms to bridge the productivity gap. Encouraging market diversification and export expansion will strengthen Latvia's position within the global agricultural market and reduce its dependence on a narrow range of products.

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The results of this study are consistent with previous research that underscores the importance of economic efficiency, technological advancement, and institutional support in determining agricultural competitiveness. For example, studies by Streimikiene et al. (2024) and Ivanova et al. (2021) demonstrate the effectiveness of MCDM approaches like TOPSIS in ranking competitiveness factors, confirming the reliability and applicability of this methodological framework (Štreimikienė et al., 2024b). By integrating FUCOM for consistent weighting and TOPSIS for robust ranking, this study provides a systematic and transparent evaluation process that can be replicated in other regions facing similar challenges.

The findings carry important policy implications for enhancing agricultural competitiveness in the Baltic states. For Lithuania, maintaining its leading position requires export diversification and greater focus on sustainable development strategies. Estonia, with its technological strengths, must address cost inefficiencies and promote high value-added agricultural products to improve global competitiveness. Latvia, meanwhile, needs targeted investments in infrastructure, technology adoption, and market diversification to overcome structural inefficiencies and improve productivity.

While this study provides valuable insights, it acknowledges certain limitations. The reliance on expert judgment in FUCOM introduces subjectivity, which could be mitigated by incorporating data-driven approaches or machine learning tools in future research. Additionally, a longitudinal analysis capturing the dynamic nature of competitiveness over time would provide a deeper understanding of policy impacts and emerging trends. Expanding the evaluation framework to include environmental and social dimensions of sustainability will further enhance the holistic assessment of agricultural competitiveness.

In conclusion, this study contributes to the growing body of literature on agricultural competitiveness by providing a robust methodological approach and actionable insights for policymakers. The findings highlight the critical role of cost efficiency, technological advancements, and institutional support in driving competitiveness while emphasizing the importance of sustainability and resilience in the face of global challenges. This framework can serve as a valuable tool for policymakers and stakeholders in other climate-sensitive and transitioning economies seeking to enhance the performance of their agricultural sectors.

5 CONCLUSIONS:

This research set out to assess and benchmark the competitiveness of Lithuanian, Latvian, and Estonian agriculture by using an inclusive framework that takes into account various factors fundamental to the efficiency of the sector. Agricultural competitiveness is important for sustainable development of the economy in the Baltic region, as agriculture plays the role of the key industry for the development of rural areas and provides a proportion of GDP for these countries. While earlier publications focused on individual domains only, this study used a combined economic technological trade institutional and emerging sustainability lens to fill the gap.

The integration of these two approaches, FUCOM and TOPSIS, allowed performing a comprehensive and clear evaluation. Weights determining criteria importance were stable across scenarios by FUCOM, while rankings delivered by TOPSIS offered specific comparison with an ideal solution. Altogether, these methods provided a practical and cumulative way of benchmarking agricultural competitiveness.

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The analysis showed that Lithuania takes a leading position in terms of agricultural competitiveness because of cost advantage, labor productivity, and support at the state level. The described strengths enabled Estonia to take the second place, whereas Latvian weaknesses in productivity and market access assigned it the third place. These results provide actionable insights for policymakers: Lithuania should pursue its competitiveness by diversification and sustainability; Estonia needs to increase productivity through exports and innovation; Latvia needs to address its structural problems and reduce costs as well as pursue productivity upgrade and new markets.

This study focuses on the high relevance of sustainability and climate vulnerability issues when considering competitiveness of agriculture. The rivalry with other countries pushes the Baltic states to adapt to the changing trends resulting from global pressures towards the use of environmentally sustainable systems. The analysis should be carried out on other regions and sectors, and the present dimensions should also be expanded in the future research. Moreover, such research in the forms of time-related series for policy changes and the application of technological innovations would give a richer understanding of the nature of competitiveness.

Therefore, this research makes a significant methodological contribution to the study of the factors that affect the agricultural competitiveness in the Baltic region and provides practical implications for practical implementation. Lithuania, Latvia and Estonia can increase their overall impact on regional and global agricultural markets through the establishment and leveraging of competencies and overcoming specific challenges. This study not only expands the theoretical knowledge of global agriculture but also provides practical references for discovering the development patterns of sustainable agriculture.

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