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Towards Climate Neutrality via Sustainable Agriculture in Soil Management

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***Abstract* – The European Green Deal sets an ambitious target for Europe to reach climate neutrality by 2050. This commitment will be a challenge, particularly in the context of agriculture, as the sector is responsible for sustainable development and food security. However, one of the primary sources of GHG emissions from the agricultural sector is the treatment of soils using nitrogen fertilizers for crops, especially grain crops. This paper aims to assess the GHG mitigation perspective for soil management in the Baltic States and, in particular, to analyse the grain sector in light of sustainable agriculture and towards climate neutrality. To achieve the aim of the study, the analysis was performed in two parts. Firstly, historical and projected GHG emissions of the Baltic States and mitigation measures on agricultural soil management, including cereal growing were analysed as these emissions show a growing tendency. Thus, the study analyses GHG emission trends, including possible mitigation measures for soil management in the Baltic States. The results indicated that for GHG reduction from agricultural soils, some cost-effective measures could be considered for the future, such as the zero-emissions on-farm machinery and equipment, low or no-tillage, or N-inhibitors on pasture. Secondly, as the GHG emissions from cereals increase, potential alternatives to the use of grain production have been explored to assess the highest possible added value from the product use, thus also contributing to GHG reduction. In this regard, according to scientific literature, a survey was created in the form of a questionnaire based on 32 alternatives, 4 large product groups, and 4 criteria for cereal and straw processing. The respondents were requested to provide an assessment of alternatives, and consequently, a multi-criteria decision analysis (MCDA) was performed using the TOPSIS method. The results reveal the best alternatives from each of the product groups consequently is flour from food products, minerals from a pharmaceutical, biogas from a form of transport and reusable tableware from straw-based products, as a possible cost-effective mitigation measure for soil management from the perspective of the development of sustainable agriculture sector and the transition towards climate neutrality**

***Keywords* – Agricultural soils; cereals; GHG emissions; grain; high value-added products; mitigation measures**

1. INTRODUCTION

In 2020, the European Commission (EC) adopted the European Green Deal [1] and, based on its framework, has launched several initiatives that deal with agricultural issues and rural areas. It is planned that these initiatives will help to achieve an ambitious climate target, with the Farm to Fork Strategy [2], the European Climate Law [3], and the Circular Economy Action Plan [4]. At the European Union (EU) level, the Member States collectively committed

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to reducing GHG emissions by at least 55 % by 2030 compared to 1990 levels [5]. In 2021, the EU launched the 'Fit for 55 package', including targets for each Member State within this framework [6], [7]. Negotiations on specific targets are ongoing, however, without any innovations, investments or employment creation, it will not be possible to decrease GHG emissions in the agricultural sector.

The EU Common Agricultural Policy (CAP) is one of the central policies driving agricultural development. The reform of the CAP is now increasingly focused on the joint goals of sustainable natural resources management and climate action [8]. In June 2018, the EU agreed to further integrate climate change action into the CAP by including renewable energy production and improving energy efficiency [9], [10]. Direct payments (up to 40 %) are also planned to achieve climate and environmental goals as part of these changes. Each EU Member State, including the Baltic States must prepare a CAP strategic plan [11], considering recommendations designed by EC for each Member State [11], to achieve specific CAP aims, including climate change and GHG emissions mitigation. The recommendations for the Baltic countries mainly relate to increasing nutrient use efficiency, improving nutrient management, encouraging carbon farming, improving management practices for carbon-rich soils and peatlands, and sustainable crop rotation [11].

According to the data published by Eurostat, cereals are one of the most widely grown crops in the Baltic States. If compared to 2005, cereals for the production of grain in 2019 increased by 29 % (EE), 56 % (LV) and 41 % (LT), respectively, and this growing tendency has also been observed in future projections. Additionally, based on the Baltic States GHG inventories and projection reports, the GHG emissions from soil management constitute approximately 50 % of total agriculture GHG emissions. Consequently, to achieve the goals mentioned above and the targets, it is essential that efforts are made to simultaneously produce products with high added value without increasing GHG emissions. Therefore, a well-considered pathway toward transition to climate neutrality in this field is crucial.

2. LITERATURE REVIEW

Analysing available sources on the GHG emissions from the agriculture sector, it can be observed that the most significant part of emissions comes from agricultural soil management, approximately 50 % in the countries evaluated [12]–[18]. Fig. 1 demonstrates GHG emissions per hectare of utilized agricultural area. This analysis reveals differences in farming practices and land use, and indicates how different land use and farming practices in countries leads to differences in emission intensities. Lithuania has the highest emissions per hectare of the utilized farm area among the three Baltic countries, therefore, this indicates a higher level of intensification of farming activities.

According to the FAO (Food and Agricultural organization of the United Nations) database, GHG emission intensity by unit of cereals was calculated (see Fig. 2) to evaluate the significance of the product. Fig. 2 shows that the highest GHG emissions per unit of cereal product is in Estonia, followed by Lithuania and Latvia [19]. Over the years, the cereals harvest in Latvia and Lithuania has increased, and the highest harvest was experienced in 2020. Comparing the year 2000 to 2020, it can be concluded that the yields in Latvia and Lithuania have increased by 79 % and 41 %, respectively [19].

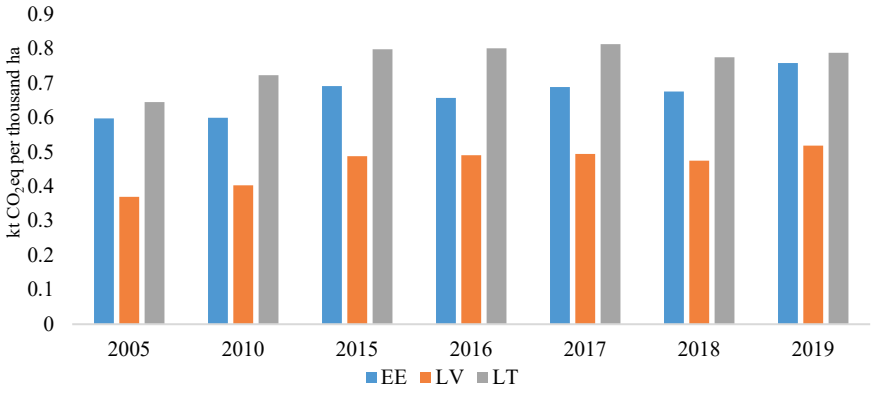


Fig. 1. GHG emissions per agricultural area (kilotons CO_2 eq. per thousand hectares) [12].

To contribute to climate neutrality and achieve long-term sustainable farming following sustainability criteria, the Baltic States will need to deal with environment, climate, productivity and effectiveness aspects on the farm. Additional measures will have to be developed to reduce emissions while considering growing high-value-added products for use. One of the activities could be the development of national models and parameters (e.g. emission factors) and improvement of data gathering to evaluate measures and subsequently track their effectiveness.

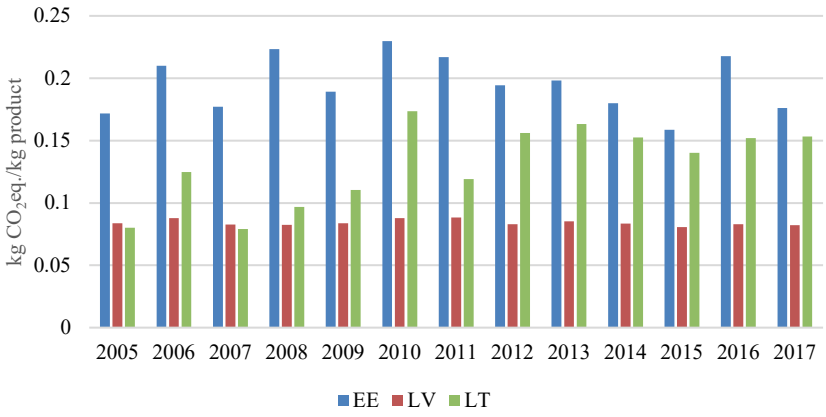


Fig. 2. GHG emission intensity [19].

Crops play an essential role in sustainable food, feed, fibre and energy production; grain crops can be used as raw materials in the production process of various products [20]–[22]. Perennial cereals may solve some of the current problems in Western Europe (e.g. control of soil erosion, reduction of nitrate leaching), however various other issues still need to be resolved [23]. Even though the farming systems can easily be adapted in rural areas, there are still questions about integration and compatibility with the existing farming systems [24]. Depending on production priorities, farm policy and markets, farmers may choose to grow perennial cereals for a variety of reasons including:

1. Environmental objectives (water protection, carbon sequestration, soil health and biodiversity conservation).
2. Strategies of crop production systems (diversification of cereals, improvement of soil fertility, reduction of operating costs).
3. Production purpose and value (dual use of feed grain) [25], [26].

Nitrogen fertilization significantly affects wheat productivity, as a considerably higher yield was observed for fertilizers unlike fertilizers non-fertilizers (+0.8 t –1 on average over two years) [27], but unfortunately at the same time, N_2O emissions are growing.

3. MATERIALS AND METHODS

This study has been developed in two parts, using several methodical approaches to achieve the aim of the study.

In the first part, the available literature has been examined together with the comparative analysis method to assess GHG emission trends and mitigation measures for soil management. As the management of agricultural soils forms the most significant part of GHG emissions, it was analysed based on GHG inventories and using the fourth biennial reports submitted by the Baltic countries to the United Nations Framework Convention for Climate Change (UNFCCC) [28].

In the second part, the literature review was first carried out. Based on this assessment, a questionnaire was developed to evaluate the use of cereals and straw for 4 groups (food, pharmaceutical, straw products, and transport).

Then, an electronic survey was developed and sent to respondents with a request to provide an assessment of cereals and straw use. Ranking matrices were created within the questionnaire, where alternatives had to be assessed according to criteria to obtain the evaluation for each cereal and straw product. All respondents provided their assessment considering the significance of each bar, from 1 to 5, where the rating '1' had the lowest weight, but the rating '5' was the bar with the highest rating.

The following four aspects were selected:

1. Availability of technology and efficiency;
2. Cost-effectiveness and sustainability;
3. Impact on the environment and climate change;
4. Socio-economic aspect.

Participants in the survey were selected based on their experience and knowledge of the sector. The questionnaire was sent to 20 experts and responses were received from all the respondents. In order to achieve maximum response from respondents and to provide qualitative assessments, the survey was not publicly posted on a social networking platform, but sent in person to respondents. In the questionnaire, 25-grain products were selected and divided into three groups – food products, pharmaceutical products, products used for transport, and 7 straw products that were split into a separate group. The following grain products were selected – grains for export; flour; bread; pasta; noodles; groats; pearl barley; muesli; gluten; starch; alcohol; kvass; beer; coffee; oil; ethyl alcohol; antioxidants; vitamins; minerals; lignans; proteins; bioethanol; biogas; biohydrogen. Selected straw products included litter in barns, pellets, fibres, disposable tableware, drinking straws, reusable tableware and bioplastic.

Once the assessments have been obtained, a MCDA was performed using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) decision analysis method that is one of the most used methods in working with MCDA [29]. Analysis of the results based on MCDA TOPSIS were carried out in two steps to determine the best alternative for

each of the product groups separately. Once the alternatives with the highest single variation ratio under each product group were obtained, then additional MCDA analysis was performed to determine the leading alternative. The evaluation process is presented in Fig. 3.

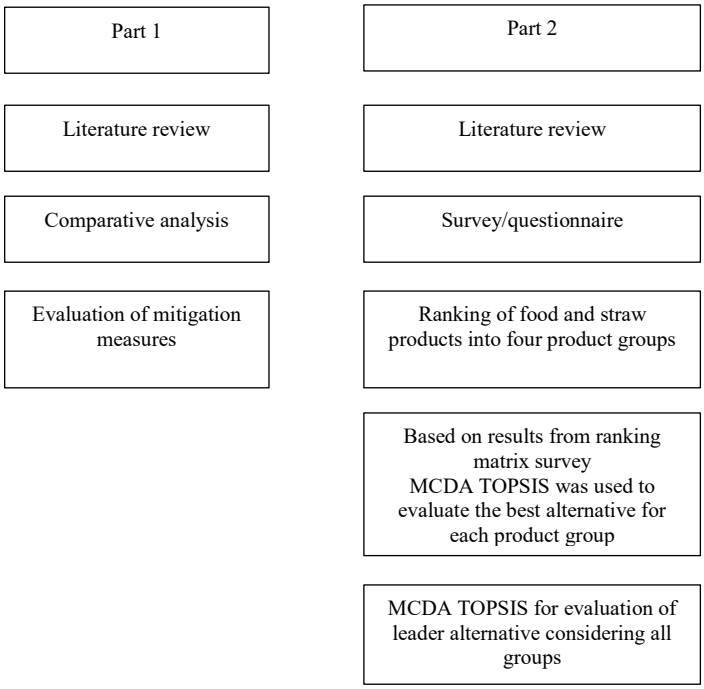


Fig. 3. Framework of methodology.

4. RESULTS

4.1. Possible Mitigation Measures in the Future for Agricultural Soil Management

In order to evaluate a move towards climate neutrality in the agriculture sub-sector of soil management, historical and projected agricultural soils N_2O emissions converted to common unit of the carbon dioxide equivalents (CO_2eq.) using a 100-year conversation factor with climate-carbon feedback of 298 for N_2O [30] value estimates, as well as mitigation measures of the Baltic states were obtained and examined using the comparative analysis method from publicly available databases [12], [19] and country reports [13]–[18]. Historical and projected emissions at the aggregate level with existing measures (WEM) show an increasing tendency for the agricultural soils (see Fig. 4).

Based on the literature review [13]–[18] key mitigation measures with estimated mitigation impact in the agricultural sector have been summarized in Table 1.

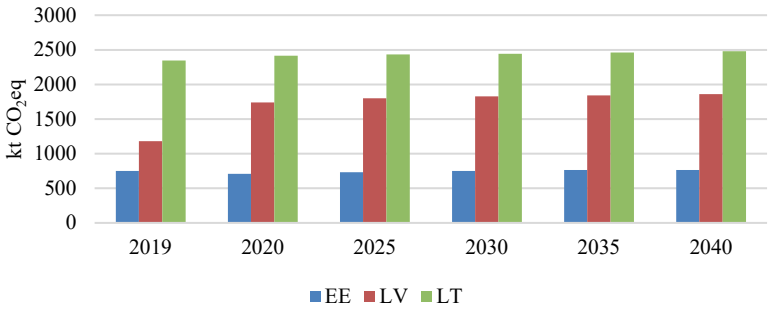


Fig. 4. GHG emissions (historical and projected) from agricultural soils [13]–[18].

TABLE 1. KEY POLICIES AND MEASURES USED IN THE AGRICULTURAL SECTOR IN BALTIC COUNTRIES [16]–[18]

Country	Key policies and measures	Estimate of mitigation impact in 2020, kt CO_2 eq.	Assessment of mitigation impact in 2030, kt CO_2 eq.
EE	ERDP for 2014–2020 (agriculture sub-measures)	n/a	n/a
	Climate Change Mitigation and Adaptation Action Plan in the Agricultural Sector 2012–2020	n/a	n/a
	Estonian Organic Farming Development Plan 2014–2020	n/a	n/a
LV	Increased land area under organic farming relative to total agricultural land	213	370
	Growing of legumes	66.1	66.1
	Support for advancing precision farming technologies and livestock feeding practices, promoting the reduced use of synthetic nitrogen, including biogas production	n/a	n/a
	Maintenance of amelioration systems	n/a	n/a
LT	Implementation of the EU Nitrates directive	100.00	n/a
	Sustainable farming (Lithuania's Rural Development Programme 2014–2020)	n/a	n/a
	Balanced use of mineral fertilizers	n/a	353.90

According to the evaluation of key policies and standards for decreasing GHG in Baltic countries, there are standard features, for example, future support to precision farming practices, promotion of growth of protein crops, and practices promoting to reduce synthetic N use, including biogas production.

Despite various GHG reduction measures [31], there is an upward trend in emissions from agricultural soils (Fig. 5). It is therefore necessary to introduce additional mitigation measures in order to move towards sustainable agriculture and thus towards climate neutrality [31].

Based on literature research [32], [33] significant measures to reduce GHGs from agricultural soil management were selected for use in the Baltic States (see Table 2).

The measures summarized in Table 2 suggested to be analysed for each of the Baltic States, considering the specific national circumstances for policy makers to promote changes in soil management in the agricultural sector.

TABLE 2. TOP MEASURES FOR GHG DECREASE FROM AGRICULTURAL SOIL MANAGEMENT BASED ON [32]–[42]

Name of Measure	Short description	Costs McKinsey & Company research	OECD	LAU research
Zero-emissions on -farm machinery and equipment	Replacement of traditional equipment.	~537 $MtCO_2$ eq. – at cost savings of ~ EUR 146 per tCO_2 eq. [32]		
Apply nitrification inhibitors on pastures	Arise primarily from applying (synthetic and organic) N to arable crops and grasslands and the direct deposition of N by grazing animals. Significant reduction in nitrous oxide emissions from ruminant urine.	~123 $MtCO_2$ eq. – at cost of ~ EUR 10 per tCO_2 eq. [33]	10–55 EUR/tCO_2eq.	Costs ~18 EUR ha^{-1}.
Scale low- and no-tillage practices	Reduce fuel usage and denitrification, in turn reducing emissions. In aggregate, these practices have been shown to deliver an 18 % reduction in yield-scaled nitrous oxide emissions in dry environments, in addition to an up to 75 % reduction in on-farm fuel usage.	~119 $MtCO_2$eq., at cost savings of ~ EUR 26 per tCO_2eq. [34]		At cost savings of 200 EUR ha^{-1}.
Expand adoption of controlled-release and stabilized fertilizers	Moving farmers away from traditional fertilizers and toward controlled-release fertilizers. An alternative is slow- or controlled-release stabilized fertilizers, which ensure that applied nitrogen is available to plants precisely when needed, resulting in less nitrogen loss to the environment.	~75 $MtCO_2$ eq., at the cost of ~ EUR 42 per tCO_2eq. [35]	143–212 EUR/tCO_2eq.	~76.60 EUR ha^{-1}.
Expand use of feed-grain processing for improved digestibility	Given constant levels of protein demand, such feed-grain processing methods cut projected GHG emissions through improved productivity (up to 5 %, depending on the region) and reduced enteric fermentation (about 15 % fewer kilograms of methane per head).	~219 $MtCO_2$eq., at cost savings of ~ EUR per 2 tCO_2eq. [36]		No additional costs.
Precision nutrient application		EUR 212/t CO_2eq. [37] (savings EUR (175)/tCO_2eq) [38]		

Based on the analysis of mitigation measures in literature [32]–[42], some cost-effective measures for GHG reduction from agricultural soils (see Table 2) could be considered with the detailed analyses of advantages and disadvantages in the future for the Baltic countries, for example:

- Zero-emissions on-farm machinery and equipment;
- Low or no-tillage;
- N fixing rotation;
- N-inhibitors on pasture.

4.2. Evaluation of Alternatives for Cereal Use

The analysis of survey results of alternatives considering the technology availability and efficiency, cost-effectiveness and sustainability, impact on the environment, climate change

and socio-economic aspect for: each food group, pharmaceutical products, transport, and straw product group are displayed in Fig. 5.

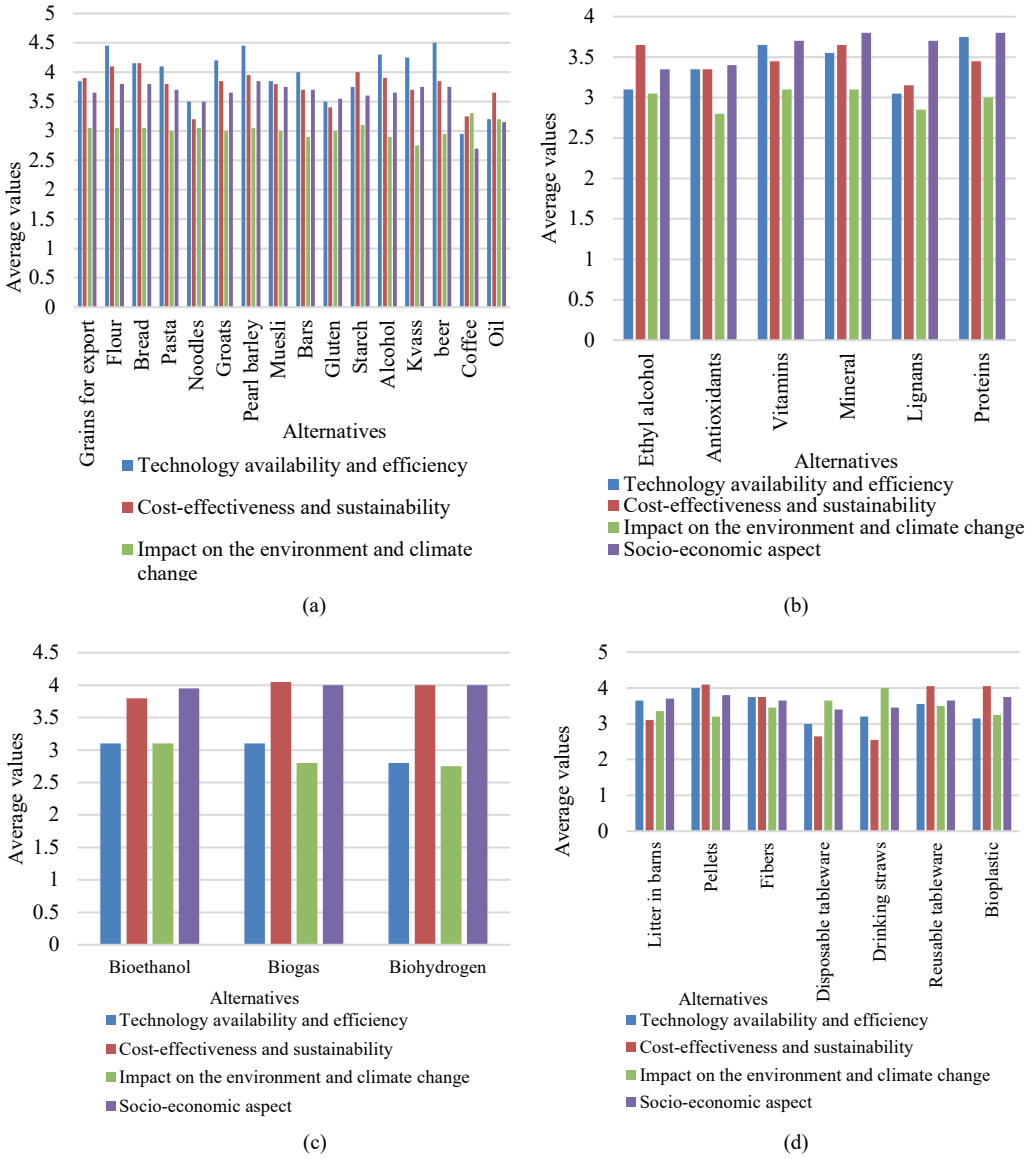


Fig. 5. Average rating of respondents for the groups of: a) food; b) pharmaceutical; c) straw products and d) the transport sector.

According to data in Fig. 5:

a) presents the data obtained for the food products represented by sixteen alternatives – grains for export, flour, bread, pasta, noodles, groats, pearl barley, muesli, gluten, starch, alcohol, kvass, beer, coffee and oil;
b) shows data obtained from the group of pharmaceutical products represented by six alternatives – ethyl alcohol, antioxidants, vitamins, minerals, lignans and proteins;
c) shows the results for the transport products with its three alternatives –

bioethanol, biogas and biohydrogen;

d) shows the results for the straw product group with its seven alternatives – barn litter, pellets, fibres, disposable tableware, drinking straws, reusable tableware, and bioplastics.

The highest assessment of products by criterion according to the survey is presented in Table 3.

TABLE 3. HIGHEST ASSESSMENT OF PRODUCTS BY CRITERION

Criterion	a) Food products	b) Pharmaceutical products	c) Transport	d) Straw
Technology availability and efficiency	beer, flour, pearl barley	proteins	bioethanol, biogas	pellets, fibres and litter in the barn
Cost-effectiveness and sustainability	bread, flour, starch	ethyl alcohol, minerals, vitamins, proteins	biogas	pellets, bioplastics reusable tableware
Impact on the environment and climate change	coffee, oil, starch	ethyl alcohol, vitamins, minerals	bioethanol	drinking straws, disposable tableware, fibres
Socio-economic aspect	pearl barley, flour, bread	proteins, minerals, vitamins, lignans	biogas and biohydrogen	pellets, bioplastics, litter in barns

The MCDA TOPSIS analysis was performed to summarize the results obtained from the survey. Given a large number of alternatives (total of 32), 4 MCDA models were initially developed (see Fig. 6., graphs (a)–(d) accordingly). MCDA for food (see Fig. 6(a)) was represented by 16 alternatives, MCDA for pharmaceuticals (see Fig. 6(b)) with its six alternatives, MCDA for products use in the transport sector (see Fig. 6(c)) and MCDA for straw products (see Fig. 6(d)).

According to MCDA TOPSIS analysis, the best possible alternatives include:

- For the food product group: flour with a uniform variation ratio of 0.89, followed by bread muesli (0.83), compared with the lowest rating which is coffee with a uniform variation ratio of 0.20;
- For pharmaceutical products: minerals (the uniform ratio of variation of minerals was 0.83, that is 0.67 units more compared to lignans, which received the lowest rating 0.16);
- For the products used for transport: biogas with a uniform variation ratio of 0.63 followed by bioethanol (0.58) and biohydrogen (0.37);
- For the straw product group: reusable tableware (0.85), followed by pellets (0.83) and bioplastic (0.77).

Finally, the MCDA TOPSIS method analysis was used to determine which alternative would be the best for each of the four product groups mentioned above. In the analysis, four alternatives were selected, one from each of the product groups, which previously had the highest single variation ratio. The summarized results indicated the alternative with the highest added value for each assessed group (see Fig. 7. According to the MCDA TOPSIS analysis, the best alternative was minerals with a uniform coefficient of variation of 0.652, followed closely by biogas with a constant coefficient of variation of 0.647.

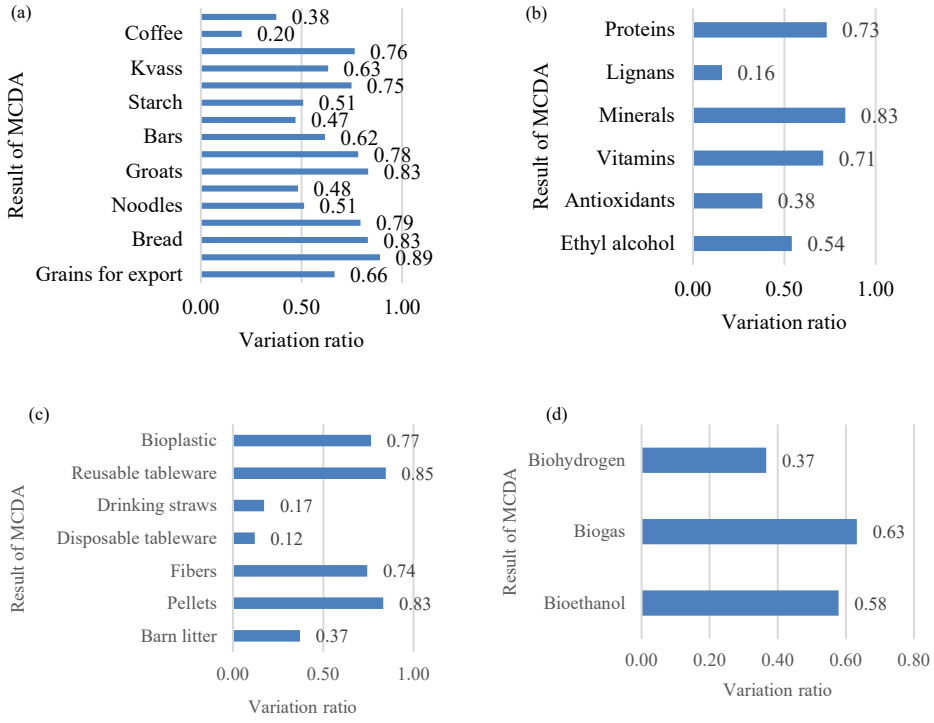


Fig. 6. MCDA TOPSIS analysis for the groups of: a) food; b) pharmaceutical; c) transport sector and d) straw products.

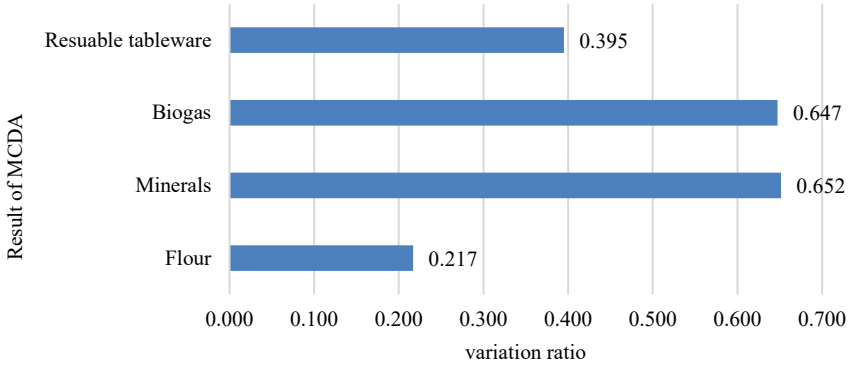


Fig. 7. Summary results of the alternatives with the highest added value for each assessed group.

4. DISCUSSION AND CONCLUSIONS

The paper provides insight into the possibility of moving towards climate neutrality via sustainable agriculture in soil management. The research was done in two parts. The following conclusions can be drawn from the first part:

1. Management of agricultural soils is one of the most significant sources of GHG emissions from the agricultural sector in the Baltic countries (50 % of emissions from total agriculture emissions in the countries analysed). Therefore, actions should be taken to decrease these sectoral emissions already by 2030, to move on to sustainable agriculture and contribute to climate neutrality by 2050.
2. A growing amount of cereals show an increasing trend, with increases in GHG emissions as well.
3. Based on the literature analysis, mitigation measures for the management of soils are an essential component to move towards climate neutrality.
4. According to the analysis of mitigation measures, some cost-effective measures for GHG reduction from agricultural soils could be under consideration in the future in the Baltic countries, for example, zero-emissions on-farm machinery and equipment, low or no-tillage, N-inhibitors on pastures.

The cultivation of cereals in the Baltic States has an increasing tendency. Therefore, a survey was created in the form of a questionnaire for the assessment of cereals and straw used to determine possible future alternatives. According to the performed qualitative results based on experts' opinions and MCDA TOPSIS method, the best alternative for the food group is flour, for pharmaceuticals – minerals, for transport products – biogas, and for straw products, the highest rating was given to reusable tableware. However, comparing all four groups, the best alternative turned out to be minerals that are important for human health. In addition, the results of this paper could be beneficial for farmers to get insight into useful GHG mitigation measures and achieve higher added value from growing cereals. Regarding the second part of the research, an additional investigation for the quantitative method application would be useful in the future, to evaluate more precise cereal product use not only for farmers but also for more effective decision making in the agricultural sector.

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