RĪGAS TEHNISKĀ UNIVERSITĀTE

Agita Gancone

TRANSITION TOWARDS RESULT-BASED AGRICULTURE SECTOR AND CLIMATE TARGETS

Doctoral Thesis

RTU Press
Riga 2022

RIGA TECHNICAL UNIVERSITY
Faculty of Electrical and Environmental Engineering
Institute of Energy Systems and Environment

Agita Gancone
Doctoral Student of the Study Programme “Environmental Science”

TRANSITION TOWARDS RESULT-BASED AGRICULTURE SECTOR AND CLIMATE TARGETS

Doctoral Thesis

Scientific supervisors

Professor Dr. habil. sc. ing.
DAGNIJA BLUMBERGA

Professor Dr. sc. ing.
JEĻENA PUBULE

RTU Press
Riga 2022

Gancone, A. Transition Towards Result-Based Agriculture Sector and Climate Targets. Doctoral Thesis. Riga: RTU Press, 2022. 164 p.

Published in accordance with the decision of the Promotion Council "RTU P-19" of 25 March 2022, Minutes No. 153.

ANOTĀCIJA

Līdz 2050.gadam Eiropas Savienībā ir noteikts mērķis sasniegt klimatneitralitāti, kas nav iespējams bez nozaru būtiskas pārkārtošanās un inovatīvu tehnoloģiju ieviešanas nacionālā līmenī. Lauksaimniecības sektorā siltumnīcefekta gāzu (SEG) samazinājums ir liels izaicinājums, bet tajā pašā laikā iespējams ar pārdomātiem uz rezultātiem balstītiem SEG samazinošiem pasākumiem.

Promocijas darba mērķis ir izstrādāt integratīvu lēmumu pieņemšanas metodiku SEG emisiju samazināšanas pasākumu novērtēšanai lauksaimniecības sektorā, tādējādi virzoties uz rezultātu balstītu lauksaimniecības sektoru un klimata neitralitāti no klimata pārmaiņu mazināšanas izvērtēšanas viedokļa.

Darba mērķa sasniegšanai ir izvirzītie uzdevumi ietver analizēt un atlasīt vides un ekonomiskās darbības rādītājus lauksaimniecības sektora ekoefektivitātes novērtējumam, izmantojot regresijas analīzes metodi, atlasīt agrovides radītājus pamatojoties uz teorijā balstītu pieeju, lai izstrādātu priekšlikumu modelēšanas ietvaram politikas veidotājiem un lēmumu pieņēmējiem SEG emisiju samazināšanas novērtējumam lauksaimniecības sektorā, veikt oglekļa bilances analīzi saimniecību līmenī biogāzes ieguvei no kukurūzas, lai būtu iespējams novērtēt kopējo ietekmi uz vidi, sarindot bioresursus biogāzes ražošanai un graudaugu izmantošanai, novērtējot dažādus kritērijus un izmantojot daudzkritēriju lēmumu analīzes metodi, prioritizēt vēsturiskos un pašreizējos SEG samazināšanas pasākumus lauksaimniecības sektorā balstoties uz Delphi pieeju un daudzkritēriju lēmumu analīzi, izmantojot TOPSIS metodi, lai novērtētu virzību uz rezultātiem balstītu lauksaimniecību un veicinātu klimata mērķu sasniegšanu, izstrādāt un piedāvāt integratīvu lēmumu pieņemšanas analīzes metodiku klimata pārmaiņu mazināšanas pasākumu izvērtēšanai un virzībai uz rezultātiem balstītu lauksaimniecības sektoru un klimata mērķu sasniegšanu.

Darbā izskatītas vairākas jaunas pieejas, kuras iepriekš politikas plānošanā nav izmantotas, uz rezultātiem balstītas lauksaimniecības veicināšanā, lai tādejādi sniegtu ieguldījumu virzībā uz klimata mērķu sasniegšanu.

Promocijas darbs ir veidots kā publikāciju kopa, kas sastāv no sešām tematiski vienotām zinātniskajām publikācijām, kas tapušas doktorantūras laikā un ietver galvenās SEG emisiju problēmas lauksaimniecības sektorā. Tās ir publicētas enerģētikas un lauksaimniecības tēmām veltītos žurnālos un indeksētas starptautiskajās datubāzēs *SCOPUS* un *Web of Science*. Pētījuma rezultāti var tikt izmantoti valsts, vietējā un nozaru līmeņa organizācijām un iestādēm, ieinteresētajām personām un zinātniekiem.

Promocijas darbs sastāv no ievada un četrām daļām. Ievada daļā iekļauta tēmas aktualitāte, hipotēze, mērķi, darba uzdevumi, darba struktūra un informācija par darba aprobāciju. Promocijas darba pamatdaļā sniegts ieskats izmantotajā literatūrā, iekļauts apraksts par metodēm, kas izmantotas pētījuma uzdevumu risināšanā, kā arī iekļauts iegūto rezultātu apraksts. Darba noslēgumā akcentēti galvenie secinājumi par promocijas darba rezultātiem un apspriesti tālākie soļi konkrētas jomas pētniecībā.

ANNOTATION

By 2050, the European Union has set the goal of achieving climate neutrality, which is not possible without significant restructuring of industries and the introduction of innovative technologies at the national level.

In the agriculture sector, GHG reduction is a major challenge, but at the same time possible with smart, result - based GHG reduction measures.

The main aim of the Thesis is to develop an integrative decision-making methodology for GHG emission reduction measures evaluation in the agriculture sector, thus moving towards the result-based agriculture sector and climate neutrality from the perspective of evaluation of climate change mitigation.

In order to reach the aims of the Thesis, the following tasks have been set to achieve the goals of the work, to analyze and select environmental and economic performance indicators for the assessment of the eco-efficiency of the agriculture sector using the regression analysis method, select agri-environmental indicators based on a theory-based approach to develop proposals for a modelling framework for policymakers and decision-makers to assess GHG emission reductions in the agriculture sector, carry out a farm-level analysis of the carbon balance for biogas production from maize to assess the overall impact on the environment, ranking bioresources for biogas production and cereal use, evaluating various criteria and using a multi-criteria decision analysis method, prioritize historical and current GHG reduction measures in the agriculture sector based on the Delphi approach, multi-criteria decisions analysis using the TOPSIS method to assess progress towards result-based agriculture and contribute to achievement of climate goals, to develop and propose an integrated decision-making analysis methodology for evaluating climate change mitigation measures and to move towards result-based agriculture sectors and climate goals.

The research presents several novel approaches, previously not been used for policy planning to identify the GHG reduction measures in agriculture sector to contribute the achievement of climate goals. The Thesis is designed as a set of publications consisting of six thematically unified scientific publications created during the doctoral program and includes the main GHG emission problems in the agriculture sector. They are published in journals on energy and agriculture and indexed in the international database *SCOPUS* and *Web of Science* database.

The results of the research can be used for national, local and sectoral level organisations and governmental authorities, stakeholders and scientists.

The Thesis consists of an introduction and four parts. The introductory part includes the topicality of the subject, hypothesis, goals, tasks, structure of the work and information about the approbation of the work. The main part of the dissertation provides an insight into the literature used, a description of the methods used to solve the research tasks, as well as a description of the results obtained. At the end of the work, the main conclusions about the research results are emphasized and further steps in research in a specific field are provided.

ACKNOWLEDGMENT

I would like to express my gratitude and appreciation for the immense support, guidance and encouragement, and to thank everyone who has assisted me during my Doctoral studies. I would like to sincerely thank my scientific supervisors Professor Dagnija Blumberga and Professor Jelena Pubule, who gave me the strength and inspiration to start Doctoral studies and encouraged me to work hard towards my goal. There were a lot of doubts, but Professors Dagnija Blumberga and Jelena Pubule motivated and helped me with the deep discussions to overcome these doubts and complete the Thesis.

I also would like to thank Ketija Bumbiere for interesting, collaborating work and all the authors of scientific articles who took the time out of their busy schedules to help complete my Doctoral thesis. Additional gratitude is offered to Ieva Līcīte, Laine Lupkina, Ingeborga Linde and other colleagues for encouragement, long discussions and for help to study and better understand more detailed GHG mitigation possibilities in the agriculture sector.

Finally, I wish to thank my family and friends for their moral support during the preparation of my Thesis. I could not have completed my research without the support of all these wonderful people!

This work has been supported by the Latvian Council of Science, project "CO_2 Deal: Effective Valorisation of CO_2 for Decarbonised Regional Development", project No. lzp-2020/1-0302 and by the Ministry of Economics of the Republic of Latvia, the project "Energy and climate modelling towards net zero emissions", project No. VPP-EM-2018/NEKP-0001.

ENERĢĒTIKAS UN KLIMATA MODELĒŠANA VIRZĪBĀ UZ OGLEKĻA NEITRALITĀTI
ENERGY AND CLIMATE MODELLING TOWARDS NET ZERO EMISSIONS

VPP Valsts pētījumu programma

FLPP FUNDAMENTAL AND APPLIED RESEARCH PROJECTS

CONTENTS

LIST OF ACRONYMS AND ABBREVIATIONS

EU	European Union
EC	European Commission
IPCC	Intergovernmental Panel on Climate Change
GHG	Greenhouse gas
GWP	Global warming potential
GDP	Gross domestic product
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
MCDA	Multi criteria decision analysis
CO_2	Carbon dioxide
N_2O	Nitrous oxide
CH_4	Methane
TOPSIS	The Technique for Order of Preference by Similarity to Ideal Solution
CSA	climate smart agriculture
NECP	National Energy and Climate Plan
ETS	Emissions Trading System
FAOSTAT	Statistics database of Food and Agriculture Organization of the United
UNFCCC	United Nations Framework Convention on Climate change `
CSB	Central Statistical Bureau
ETS	European Union Emissions Trading System
IPPU	Industrial processes and product use
LULUCF	Land use, land use change and forestry
WEM	With existing measures
WAM	With additional measures
CAP	Common agricultural policy
NDC	Nationally Determined Contribution
MMS	Manure management systems
LCC	Life Cost Cycle
DEA	Data envelopment analysis
EIOA	Environmental Input-Output Analysis
PA	Process Analysis
MACC	Marginal abatement cost curve
LEGMC	Latvian Environment, Geology and Meteorology Centre
CSB	Central statistical bureau
MRV	Monitoring, reporting and verification
COP	Conference of the Parties

INTRODUCTION

An analysis of the current climatic conditions as well as the future climate change scenarios demonstrate that the global climate warming trends will continue throughout this century. Undeniably the societies, industries, and the countries will be faced with this great challenge in the future.

In the territory of Latvia, the most significant climate changes in the longer term will be related to extreme values of climatic parameters and more frequent unusual and extreme weather conditions.

According to the United Nations Framework Convention on Climate Change (UNFCCC) and its Paris Agreement, to limit the global warming between 1.5 °C and 2 °C, global net carbon dioxide (CO_2) emissions must be decreased to zero in 2050.

Latvia as a Party of the Paris Agreement is among those European Union (EU) Member States committed to achieve climate or carbon neutrality by 2050. The EU is setting a new target to reduce net emissions by at least 55 % by 2030 compared to 1990, and discussions on the new targets for Member States are ongoing. To achieve these short and long-term goals, all the involved sectors of energy, transport, industrial processes and product use (IPPU), agriculture, land use, land use change and forestry (LULUCF) and waste management must contribute to greenhouse gas (GHG) emission decrease despite that for agriculture sector it seems a more challenging task than for other sectors.

Question arises how to move towards this long-term goal and the reductions in global GHG emissions, that are needed to achieve the long-term temperature goal of the Paris Agreement, holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C, and what is the agriculture's contribution to climate change and role in mitigation?

The agriculture is a significant contributor to anthropogenic global warming and reducing agricultural emissions in this sector has a complex combination of objectives to be considered together with the climate goals, such as the food security and biodiversity. The agriculture sector keeps essential role in the Latvia's economy and plays a significant role in keeping rural areas as a habitable environment.

In 2019, the EU agriculture sector accounted for 11 % of total GHG emissions, while in Latvia it accounted for about 20 % of total GHG emissions, excluding LULUCF. Agriculture sector is second biggest contributor of total non-EU Emissions Trading System (non-EU ETS) sector's GHG emissions in Latvia (25.5 %). The largest part of emissions is related to agricultural soils (51.1 %) and enteric fermentation 38.6 % (mainly dairy and beef cattle). The GHG emission trend in recent years in the agriculture sector displays a gradual and steady increase of the GHG emissions, for example, between 2005 and 2019 it shows + 22.8 % increase [1].

According to the Latvia's National Energy and Climate Plan 2021–2030 (NECP), total GHG emissions in the agriculture sector are expected to increase for the period of 2020 to 2030, mainly in the enteric fermentation and agricultural soil categories [2]. For the agriculture sector, an improved food security and the climate smart activities (CSA) will be necessary to move towards result-based agriculture and climate goals. Result-based concept as crucial is emphasized by the EU Sustainable Carbon Cycles communication of December 2021 that encourages move from action to result-based approach. Therefore, the Thesis outlines a discussion of result-based agriculture in Latvia from the perspective of achieving climate goals.

In addition, there is no system in place to evaluate these activities and the mitigation measures as well as no methodological, systematic approach, thus policy planning process is mostly based on qualitative rather than quantitative estimates. Therefore, it is recommended to develop the overall scheme of the proposed integrative decision-making methodology for practical implementation.

The results of this research will be useful for national, local, and sectoral level of governmental authorities, as well as the stakeholders and scientists, also helping to enhance the potential to be utilized for broader societal benefit.

Relevance of the Topic

Agriculture sector (farmers, agri-food businesses, and rural communities) play a significant role in several areas of the Europe's Green Deal that was approved in 2020 as a set of overarching EU policy initiatives, including:

- contribution to Green Climate Action to achieve the European Union's climate neutrality target by 2050;
- to create a sustainable food system within the framework of the "Farm to Fork" strategy;
- to enhance plant and animal diversity in the rural ecosystem;
- to support the renewed EU Forest Strategy by maintaining healthy forests and to promote protecting natural resources such as water, air and soil.

According to ambitions of the European Green Deal, it is planned to increase the contribution of EU agriculture sector to address the climate change. To move towards climate neutrality, the EC has adopted a package of proposals “Fit for 55” aimed at making the EU climate, energy, transport, agriculture, and taxation policies ready to reduce GHG emissions by at least 55 % by 2030 compared to 1990 levels. Currently there are discussions on the proposed climate targets at the Member State level. For Latvia, instead of the approved –6 % for non-ETS sector (including agriculture) the –17 % in GHG emission reduction in 2030 compared to 2005 is planned [3]. However, agriculture is a significant source of GHG emissions in Latvia, accounting for approximately 20 % of total of its GHG emissions.

Moreover, it is planned to link the agriculture and LULUCF sectors after 2031 as a part of the “Fit for 55” package, moving the EU towards climate neutrality. In addition, one of the main policy instruments should be future Common Agricultural Policy (CAP) Strategic Plans thus introducing a more flexible performance and result–based approach that considers local circumstances and needs, while increasing sustainability ambitions at the EU level. Recently published EU Sustainable Carbon Cycles communication of December 2021 encourages massive move of EU`s agriculture from the historically widely used action-based approach towards a result-based oriented business model [4]. The Thesis is an attempt to outline the result-based agriculture discussion in Latvia.

The relevance of this research lays not only in the description of the importance of GHG reduction measures, analysis of the carbon balance at farm level, ranking of bioresources for biogas production, ways of moving towards climate neutrality; it also contributes to the development of an integrative decision-making methodology for GHG emission reduction measures in agriculture, thus moving towards result-based sector and climate goals.

The Aim of the Investigation

The main aim of the Thesis is to develop an integrative decision-making methodology for the evaluation of GHG emission reduction measures in the agriculture sector, thus moving towards the result-based agriculture sector and climate neutrality.

To achieve the aim of the research, the following tasks were carried out:

- to analyse and select environmental and economic performance indicators for the assessment of the eco-efficiency of the agriculture sector using the regression analysis method;
- to select agri-environmental indicators based on a theory-based approach to develop proposal for a modelling framework for policymakers and decision-makers to assess GHG emission reductions in the agriculture sector;
- to carry out a farm-level analysis of the carbon balance for biogas production from maize to assess the overall impact on the environment;
- to rank bioresources for biogas production and cereal use by, evaluating various criteria and using a multi-criteria decision analysis method;
- to prioritize historical and current GHG reduction measures in the agriculture sector based on the Delphi approach, multi-criteria decisions analysis using the TOPSIS method to assess progress towards result-based agriculture and contribute to climate goals;
- to develop and propose an integrated decision-making analysis methodology for evaluating climate change mitigation measures to move towards result-based agriculture sectors and climate goals.

Novelty of the Research

The novelty of the research is the cross-cutting analysis for moving towards climate neutrality and result-based agriculture sector implementation on four different, but interrelated levels: (I) farm, (II) sub-sectoral, (III) state, and (IV) international, including a comprehensive emphasis on the agriculture sector.

In order to develop an integrative decision-making methodology for the GHG reduction measures in agriculture sector, a different distribution of research methods, both quantitative and qualitative, were used.

The novelty of the research also is the use of several academic methodologies to determine the direction towards a result-based agriculture sector and climate neutrality. To date, Latvia has not developed such an integrative methodology for the evaluation/selection of result-based GHG reduction measures for the agriculture sector.

Eco-efficiency of agriculture sector was assessed at the sub-sectoral and state level via regression analysis using various sectoral indicators, and the GHG emission reduction tool with a set of indicators for the assessment of GHG emission mitigation measurements in agriculture sector was proposed.

Carbon balance analysis of substrate was used for biogas production analysis at a farm level, ranking of bioresources for biogas production in technology and sectoral level using Multi Criteria Decision Analysis (MCDA) as well as an analysis of historical and current GHG reduction measures were done in order to simultaneously move towards result-based agriculture and contribute to climate neutrality.

Using the Delphi approach and the MCDA TOPSIS method, a decision-making analysis method is proposed to be used to assess climate change mitigation measures towards a result-based agriculture sector and climate neutrality.

Finally, the author's lifetime work is related to Latvia's historical and projected GHG calculations, including in the agriculture sector. To author's knowledge, this is the for first time that an integrative decision-making methodology for the result-based agriculture and climate neutrality has been researched utilizing the author's long-term experience gathered during her work on developing a methodology for future practical implementation.

Hypothesis

The transition towards a result-based agriculture sector and climate neutrality can be effectively supported if an integrative methodology that includes sectoral indicators, a carbon balance analysis, and a decision-making analysis tool for GHG emissions mitigation measures is introduced and implemented.

Theses to be Defended

1. The agriculture sector's GHG emissions are increasing despite the planned climate change mitigation measures, and these emissions play a vital role in Latvia's progress towards climate neutrality.
2. The existing system in the selection of GHG reduction measures for the agriculture sector could significantly contribute to the achievement of climate goals.
3. A result-based approach in the agriculture sector from a climate perspective is an essential part of eco-efficiency assessment.
4. A systematic approach that includes expert analysis of GHG mitigation measures and the implementation of an integrative methodology in policy making would contribute to the progress of the result-based agriculture sector from the perspective of the climate change mitigation evaluation.

Practical Significance

The Thesis has a high practical significance in the national and European context. Findings and conclusions of this research are useful in the process of improving Latvia's agricultural policy towards result-based agriculture and climate neutrality. The research results also provide a novel an integrative decision-making methodology, which can provide a significant contribution a) for several agriculture sector stakeholders at sectoral, national, and international level; b) at a farm level, in rural advisory and training centres and in public policy planning to assess the eco-efficiency, that can be used for demonstration of sustainable and climate friendly farming; c) for decision-makers to evaluate climate change mitigation measures towards a result-based agriculture sector and climate neutrality; and d) for scientists and researchers in agricultural field that work on this research related topics.

The use of such a quantitative methodological approach can be used to assess and set both farm and national policy goals with a view to reducing GHG emissions from the agriculture sector.

Structure of the Research

The Thesis is based on six interrelated scientific publications with the comprehensive focus on the transition towards result-based agriculture and climate neutrality. Agriculture sector is wide and multifaceted, it`s transition towards result based approach is analysed from the perspective of evaluation of climate change mitigation. Based on the scientific literature review and review of national climate policy decision-making system, identification of currently weak points was done and different methods were chosen for the analysis within the Thesis with the aim to develop integrated decision-making methodology in transition to climate neutrality. The Thesis discusses climate change related problems of the sector, which are most essential in transition towards achieving climate neutrality. The selected scope of methods and problematic aspects cover different levels of the sector – farm, sub-sectorial, state and international, allowing development of integrative decision-making methodology for GHG emissions reduction evaluation of agriculture sector.

The research (I) crosses several layers of the agriculture sector and the relevant levels of the analysis; (II) develops interconnected research methods; and (III) delivers multiple GHG emission reduction, GHG mitigation measure, and carbon balance models of both scientific and practical relevance.

The graphic representation of the reserch structure is shown in Fig. 1. The investigation starts with a literature review, setting out the discussion regarding the result-based agriculture and climate targets, and outlining the experience gained so far for meeting the determined targets, as well as looking for implementation steps regarding GHG emissions reduction measures for agriculture sector in near future.

As mentioned above, the Thesis comprises six interrelated scientific publications outlining the main GHG reduction problems in the agriculture sector (Table 1).

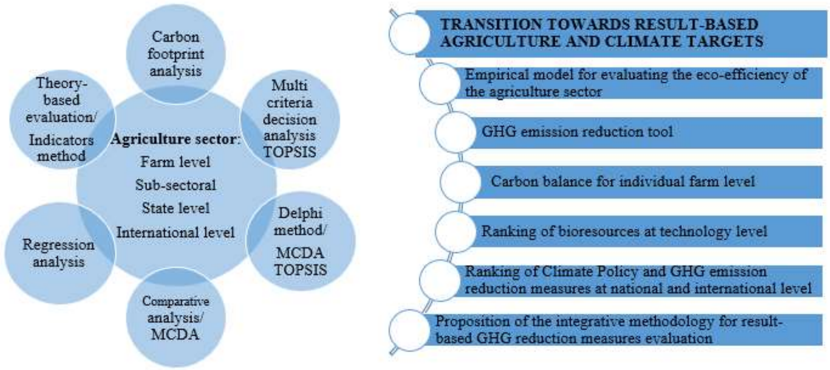

Fig.1. Research structure

Table 1

Thesis Structure and the Role of Publications

Method	Publication number	Publication title	Stage of transition	Consumer level
Regression analysis	1	Evaluation of agriculture ecoefficiency in Latvia	Empirical model for evaluating the eco - efficiency of the agriculture sector	State Sectoral
Theory-based evaluation	2	Sectoral greenhouse gas emission mitigation possibilities. Why broad spectrum of indicators is applied	GHG emission reduction model	State International
Carbon balance analysis	3	Carbon balance of biogas production from maize in Latvian conditions	Carbon balance for individual farm level	Farm level
MCDA TOPSIS method	4	Ranking of bioresources for biogas production	Bioresources ranking at technology level	Farm level State Sub sectoral
Delphi + MCDA TOPSIS method	5	Valorization methodology for agriculture sector climate change mitigation measures	Ranking of climate policy and GHG emission reduction measures at national and international level.	State Sub sectoral
Comparative analysis /MCDA TOPSIS method	6	Towards climate neutrality via sustainable agriculture in soil management	Proposition of the decision-making analysis tool	Sate Sub sectoral International

With the application of such research methods as (I) regression analysis (II) theory-based analysis, (III) carbon balance analysis, (IV) multi criteria decision analysis TOPSIS, (V) combination of the Delphi approach/MCDA TOPSIS method, and (VI) combination of the comparative analysis/MCDA TOPSIS method, the dissertation evaluates various aspects, levels, and interrelationship of the result-based agriculture sector with the aim to reveal the factors that allow the transition to climate neutrality.

In the last chapter, the results are discussed, displaying a theoretical roadmap for the implementation of GHG emission reduction measures in agriculture sector and related benefits that this process may bring.

Scientific questions related to publications are displayed in Table 2.

Table 2

Scientific questions related to the publications

Scientific questions	*Evaluation of agriculture ecoefficiency in Latvia*	*Sectoral greenhouse gas emission mitigation possibilities. Why broad spectrum of indicators is applied*	*Carbon balance of biogas production from maize in Latvian conditions*	*Ranking of Bioresources for Biogas Production*	*Valorization Methodology for Agriculture Sector Climate Change Mitigation Measures*	*Towards climate neutrality via sustainable agriculture in soil management*
assessment of the eco-efficiency of the agriculture sector, taking into account national indicators, using regression analysis	X					
selection agri-environmental indicators based on a theory-based approach to develop and recommend a modelling framework for decision-makers to assess GHG emission reductions in the agriculture sector	X	X			X	X
to carry out carbon balance			X			

Scientific questions	*Evaluation of agriculture ecoefficiency in Latvia*	*Sectoral greenhouse gas emission mitigation possibilities. Why broad spectrum of indicators is applied*	*Carbon balance of biogas production from maize in Latvian conditions*	*Ranking of Bioresources for Biogas Production*	*Valorization Methodology for Agriculture Sector Climate Change Mitigation Measures*	*Towards climate neutrality via sustainable agriculture in soil management*
analysis in farm level						
to rank bioresources for biogas production and cereal use in technology and sectoral level using multi criteria analysis			X	X		X
to prioritize historical and current GHG reduction measures to simultaneously move towards result-based agriculture and contribute to climate neutrality	X	X			X	X
to develop and propose a decision-making analysis tool to be used for evaluation of climate change mitigation measures for moving towards result-based agriculture sector and climate neutrality		X			X	X

Scientific Approbation

The results of the research have been published in scientific journals that are indexed in Scopus and Web of Science databases and have been presented at international scientific conferences.

1. Gancone, A., Pubule, J., Rošā, M., Blumberga, D. Evaluation of Agriculture Eco-Efficiency in Latvia. Energy Procedia, 2017, Vol. 128, pp. 309–315. ISSN 1876-6102. Available: doi:10.1016/j.egypro.2017.08.318.
2. Pubule, J., Gancone, A., Rošā, M., Blumberga, D. Sectoral Greenhouse Gas Emission Mitigation Possibilities. Why Broad Spectrum of Indicators are Applied. Energy Procedia, 2017, Vol. 113, pp. 377–381. ISSN 1876-6102. Available: doi:10.1016/j.egypro.2017.04.015.
3. Bumbiere, K., Gancone, A., Pubule, J., Blumberga, D. Carbon Balance of Biogas Production from Maize in Latvian Conditions. Agronomy Research, 2021, Vol. 19, No. 1, pp. 687–697. ISSN 1406-894X. Available: doi:10.15159/AR.21.085.
4. Bumbiere, K., Gancone, A., Pubule, J., Kirsanovs, V., Vasarevicius, S., Blumberga, D. Ranking of Bioresources for Biogas Production. Environmental and Climate Technologies, 2020, Vol. 24, No. 1, pp. 368–377. ISSN 1691-5208. e-ISSN 2255-8837. Available: doi:10.2478/rtuect-2020-0021.
5. Gancone, A., Pubule, J., Blumberga, D. Valorization Methodology for Agriculture Sector Climate Change Mitigation Measures. Environmental and Climate Technologies, 2021, Vol. 25, No. 1, pp. 944–954. ISSN 1691-5208. e-ISSN 2255-8837. Available: doi:10.2478/rtuect-2021-0071.
6. Gancone, A., Viznere, R., Pubule, J., Kaleja, D., Blumberga, D. Towards climate neutrality via sustainable agriculture in soil management. Environmental and Climate Technologies, 2022. vol. 26, no. 1, pp. 512–524. Available: https://doi.org/10.2478/rtuect-2022-0039.

The research results have been discussed and presented at the following conferences.

1. Gancone, A., Pubule, J., Rošā, M., Blumberga, D. Evaluation of Agriculture Eco-Efficiency in Latvia. International Scientific Conference of Environmental and Climate Technologies, CONECT, 2017 May 10–12, Riga, Latvia.
2. Pubule, J., Gancone, A., Rošā, M., Blumberga, D. Sectoral Greenhouse Gas Emission Mitigation Possibilities. Why Broad Spectrum of Indicators are Applied. International Scientific Conference of Environmental and Climate Technologies, CONECT, 2017 May 10–12, Riga, Latvia.
3. Bumbiere, K., Gancone, A., Pubule, J., Blumberga, D. Carbon Balance of Biogas Production from Maize in Latvian Conditions. Biosystems Engineering 2021 May 5–6, 2021, Tartu, Estonia.
4. Bumbiere, K., Gancone, A., Pubule, J., Kirsanovs, V., Vasarevicius, S., Blumberga, D. Ranking of Bioresources for Biogas Production. International Scientific Conference of Environmental and Climate Technologies, CONECT, 2020 May 13–15, Riga, Latvia.

5. Gancone, A., Pubule, J., Blumberga, D. Valorization Methodology for Agriculture Sector Climate Change Mitigation Measures. International Scientific Conference of Environmental and Climate Technologies, CONECT, 2021 May 12-14, Riga, Latvia.
6. Gancone, A., Viznere, R., Pubule, J., Kaleja, D., Blumberga, D. Towards climate neutrality via sustainable agriculture in soil management. International Scientific Conference of Environmental and Climate Technologies, CONECT, 2022 May 11–13, Riga, Latvia.

Other publications.

1. Gancone, A., Bumbiere, K., Pubule, J., Blumberga, D. Sustainable Biogas Application in Energy Sector. In: 2020 IEEE 61st Annual International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON 2020): Proceedings, Latvia, Riga, 5–7. November 2020. Piscataway: IEEE, 2020, pp. 494–497. ISBN 978-1-7281-9511-7. e-ISBN 978-1-7281-9510-0. Available: doi:10.1109/RTUCON51174.2020.9316593.
2. Gancone, A., Lupkina, L., et al. (2022). Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990–2020. Riga: Ministry of Environmental Protection and Regional Development of the Republic of Latvia.
3. Gancone, A., Lupkina, L., et al. (2021). Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990–2019. Riga: Ministry of Environmental Protection and Regional Development of the Republic of Latvia.
4. Dimbiere, A., Gancone, A., et al. Reporting on Policies and Measures under Article 18 of Regulation (EU) No. 2018/1999 of the European Parliament and of the Council. Ministry of Environmental Protection and Regional Development of the Republic of Latvia. 2021.
5. Priede A., Gancone A. (eds.) 2019. Sustainable and responsible after-use of peat extraction areas. The monograph. Baltijas krasti, Riga, pp. 21–54. Baltijas krasti, Rīga.
6. Gancone, A., Skrebele, A., et al. (2020). Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990–2018. Riga: Ministry of Environmental Protection and Regional Development of the Republic of Latvia.
7. Gancone, A., Skrebele, A., et al. (2019). Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990–2017. Riga: Ministry of Environmental Protection and Regional Development of the Republic of Latvia.
8. Gancone, A., Skrebele, A., et al. (2018). Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990–2016. Riga: Ministry of Environmental Protection and Regional Development of the Republic of Latvia.
9. Gancone, A., Skrebele, A., et al. (2017). Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990–2015. Riga: Ministry of Environmental Protection and Regional Development of the

Republic of Latvia.
10. Gancone, A., Skrebele, A., et al. (2016). Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990–2014. Riga: Ministry of Environmental Protection and Regional Development of the Republic of Latvia.
11. Gancone, A., Skrebele, A., et al. (2015). Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990–2013. Riga: Ministry of Environmental Protection and Regional Development of the Republic of Latvia
12. Gancone, A., Lupkina, L., et al. (2019). Latvia's Fourth Biennial Report under the United Nations Framework Convention on Climate Change. Ministry of Environmental Protection and Regional Development.

1. LITERATURE REVIEW

1.1. Agriculture sector in the context of climate goals

One of the greatest global challenges of our time for human health, security, economy and nature is climate changes. According to IPCC studies, anthropogenic global warming has already reached 1°C above pre-industrial levels and continues to rise by around 0.2 °C over the last decade [5]. To limit the global temperature rise, the comprehensive action of all countries around the world is needed to reduce the GHG emissions.

On December 2015, an important long-term instrument, the Paris Agreement, was adopted by the Conference of the Parties (COP) to the UNFCCC, which aims to strengthen global action to tackle climate change and keep global warming well below 2 °C above pre-industrial levels, and to seek to limit temperature rises to 1.5 °C, in order to significantly reduce the risks and impacts of climate change [6].

For the EU, the common EU GHG emission reduction targets have been set in 2015. Latvia's obligations in the context of the Paris Agreement were to implement the commitments made by the EU Nationally Determined Contribution (NDC), that provided a joint commitment of EU Member States to reduce GHG emissions by at least 40 % by 2030, compared to 1990 [7].

In December 2019, the EC proposed a new, extensive policy shift by issuing a Communication and Roadmap on a European Green Deal, setting out comprehensive policy initiatives [8] at the European level, aiming at making the EU climate neutral by 2050. Policy initiatives most related to agriculture sector in the context of climate goals are the Farm to Fork Strategy [9], the European Climate Law [10], and the Circular Economy Action Plan [11]. Exclusively sectorial specific policy document for agriculture is the Farm to Fork Strategy that determines matters of sustainability of food as well the support granted to farmers. This Strategy includes the following main targets: agriculture of EU be organic 25 % by 2030, decrease the utilization of pesticides by 50 % until 2030, reduce use of fertilizers by 20 % by 2030, decrease loss of nutrients in soil at least 50 %, decrease antimicrobials use in agriculture and in aquaculture by 2030 by 50 %, create food labelling sustainable, reduce wastes of food by 50 % by 2030 [9]. All of the mentioned initiatives stimulate EU`s movement to climate smart agriculture (CSA) and contribute to achievement of the sustainable development goals [9].

On June 2018, the EU agreed to further integrate climate change action into the Common Agricultural Policy (CAP) by including renewable energy production and improving energy efficiency. Significant financial stimulus and signal for agriculture sector in the climate change context is new CAP requirement to ensure contribution of 40% of the overall financial envelope to climate objectives [12],[13].

Reviewed EU`s climate aims were reflected also in December 2020, when the EU submitted its renewed EU NDC to the Secretariat of the UNFCCC on behalf of its Member States, aiming more ambitious EU GHG reduction target of at least –55 % by 2030, compared to 1990 [14].

The EU targets are divided into two parts: sectors covered by the EU Emissions Trading Scheme (EU ETS) and sectors not covered by the EU ETS with the sector of agriculture being among them.

Regarding the fulfilment of the non-ETS target, Latvia needs to ensure a 6 % reduction in GHG emissions in the period from 2021 to 2030, compared to the amount of GHG emissions from Latvia's non-ETS activities in 2005 [15].

Following the increasingly growing EU`s ambitious climate targets trend, on 14 July 2021 the EC presented a comprehensive "*Fit for 55"* package [16],[17] of the revised legislative proposals for overall transformation of the EU economy. It was designed to make the European Green Deal a success by 2030, achieving the new, enhanced EU target of at least 55 % net reduction in GHG emissions (compared to 1990) by 2050 achieving climate neutrality.

As part of the amendments of the package for Latvia is proposed to set a target to reduce its non-ETS GHG emissions in 2030 by 17 %, compared to 2005. Indeed, this goal is remarkably challenging as biogenic and thus complicate to reduce GHG emissions of the agriculture sector contributed approximately 26 % of total non-ETS emissions in 2019. However, there are still ongoing discussions on this new proposal and current numbers still may be subject to changes.

At the same time, the EU level initiatives and decisions are consecutively reflected and adapted into national level policy documents according to order Latvia is following as EU member state. At national level, to reach progress on climate neutrality and climate resilience targets including by means of agriculture sector, several important state level planning documents have been adopted or are in the process of development, as displayed in Figure 1.1.

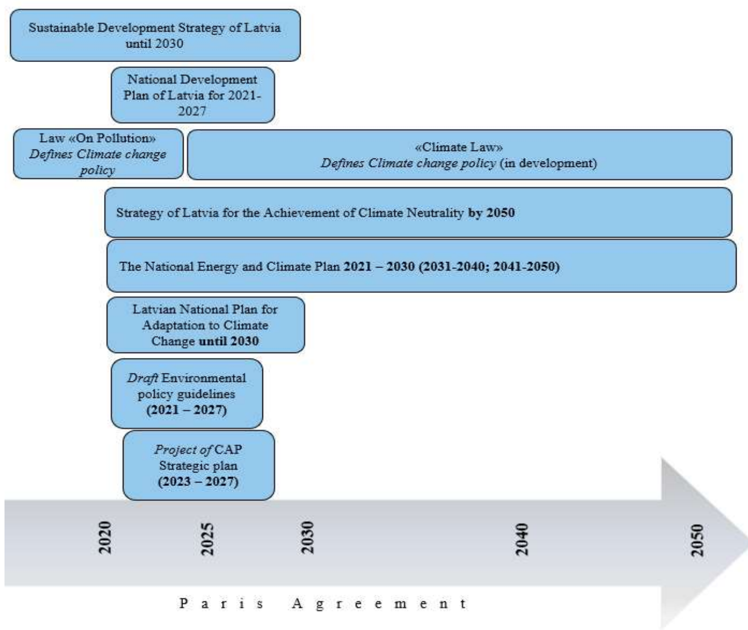

Fig.1.1. Climate policy framework related to agriculture sector in Latvia for 2020 – 2050

Considering climatic vulnerability of the agriculture sector, climate change adaptation is crucially significant component of climate smart and sustainable development pattern to be reached within the sector. In July 2019, the Cabinet of Ministers approved Latvia's Adaptation plan to climate change for the period until 2030 [18], to better adapt to the ongoing climate change and thus reduce the losses caused by climate change. Five strategic objectives have been set for its implementation, including more than 80 specific medium-term measures. The adaptation activities are based on research on risk and vulnerability assessment and identification of adaptation measures in six areas: landscape and tourism, biodiversity and ecosystem services, civil protection and disaster management, construction and infrastructure planning, health and welfare, agriculture and forestry sectors.

According to the Plan [18] the main risks identified in agriculture are freezing of crops and plantations, crop and animal diseases and pests, crop and crop loss due to rainfall at harvest, faster soil drying and prolonged heat waves. However, it should be noted that the risks are mainly economic. The social impact arises indirectly from the economic risks: as the yield of certain crops decreases, the well-being of farm owners decreases, as does the farm's ability to employ workers, thus leaving a socio-economic impact on the region where the farm is located. Taking into account risks mentioned, adaptation to climate change in agriculture sector goes hand in hand with GHG emission reduction practices. Accordingly, in January 2020, the Cabinet of Ministers approved Strategy of Latvia for the Achievement of Climate Neutrality until 2050 (Strategy of Climate Neutrality for 2050) [19], that is a long-term vision document to ensure the inclusion of basic principles of low-carbon development in all national sectoral planning documents. The Strategy offers ambitious GHG reductions in line with the scientific findings of the IPCC and the objectives of the Paris Agreement. However, it does not set out specific measures to achieve these objectives, rather, setting benchmarks for each decade. Thus, short-term goals are needed to be further developed through planning tools such as the NECP [2].

Regarding the agriculture sector, it is necessary to move on a sustainable land management policy development and implementation - according to the Strategy of Climate Neutrality for 2050. It emphasizes that land management, including LULUCF and agriculture sectors, through the technologies, sustainable management practices and efficient planning should contribute to climate neutrality without compromising economic development. In addition, possible solutions for the low carbon development for agriculture sector include [19]:

- A sustainable balance between different land uses, taking into account climate, nature protection, economic and social aspects. Sustainable land management needs to be planned at both national and regional level, considering regional specificities.
- The need to transform land from one use to another must be seriously considered in the future. For example, the establishment of unsustainable crop plantations, the expansion of agricultural land to grow bioenergy crops, which are considered to be a serious threat to biodiversity and the resilience of ecosystems to climate change, are limited. The irrational use of land has also been curtailed.
- Agriculture makes a significant contribution to bioenergy without compromising food security and CO_2 sequestration. It means without endangering biodiversity, new

varieties that are resilient to climate change and provide optimal CO_2 sequestration are selected and used, the latest generation of biofuels is designed to reduce the risk of food crops being used for bioenergy and the new technologies and methods are used at all stages of the management process, with sustainability, environmental impact, climate and health as key criteria.

- Latvian agriculture is resource efficient - high productivity is achieved, products with high added value are produced. For example, good agronomic and animal husbandry practices are followed, thus ensuring the conservation of land resources for future generations. Improved varieties and precise fertilizer application are chosen to increase productivity, as well as crop rotation involving perennial crops and legumes, as well as maintaining soil cover throughout the year in areas where erosion is possible. The use of fertilizers is carefully planned - the use of legumes as a crop rotation has reduced the doses of synthetic nitrogen fertilizer, but the cultivation of receiving plants ensures that unused nitrogen is not released into the environment. Innovative technologies are used to deliver precise fertilizer to the plants, which reduces the consumption of fertilizer and the negative impact on the environment. Maintaining soil fertility is essential as well - increasing the carbon stock in the soil. The use of manure, ensuring that it is incorporated into the soil as quickly as possible, helps to avoid soil compaction and deep ploughing. Livestock farming is planned taking into account the latest scientific findings. Feed is used that ensures optimal digestion of the animals without compromising their health. Manure storage facilities have been set up and their use is effectively controlled. On farms where economically viable, biogas is produced from the processing of manure and other organic waste. The health and welfare of farm animals is ensured.
- Innovation has been successfully implemented in agriculture as well as in other sectors of the economy. The latest scientific knowledge is used. Decisions to introduce new policies and measures are made in a sustainable way, analyzing the benefits and harms as well as the impact on other policies. This reduces emissions from the unit of agricultural production.
- Organic soils have been studied and used accordingly thus ensuring appropriate choice of land use for agricultural land areas that are not actively used for agricultural production due to various reasons (e.g., low soil quality value, large resources required for restoration of drainage systems, lack of access roads, rural configuration and location).

With the Strategy of Climate Neutrality for 2050 Latvia emphasizes the need for resource efficiency, sustainable balance between different land uses, innovation implementation, however, the result-based indicators are not set out, thus lacking the support for low carbon development in agriculture sector.

Although within these Thesis the GHG emission reduction is viewed mainly through the agriculture sector perspective, further investigations are necessary including GHG emissions and removals as part of the LULUCF sector, since agriculture land related GHG emissions has to be reported in both sectors of the National GHG inventory. Cross sectoral analysis could include agriculture related part of the energy and waste sector as well.

To track the progress in meeting EU`s climate and energy targets for all sectors including agriculture, EU countries are obliged to develop integrated national energy and climate plan (NECP).

On January 2020, the Cabinet of Ministers approved Latvia's NECP for 2021–2030 [2]. According to NECP, specific measures to reduce GHG emissions and increase CO_2 sequestration, including improving energy efficiency and promoting renewable energy sources in energy, agriculture, transport, and other sectors of the economy, as well as the promotion of research and innovation in their respective fields are in place. The long-term goal of the NECP is consequent with EU`s and Latvia`s strategic policy to promote a sustainable and climate-neutral economy.

Within the framework of the NECP, Latvia has set a GHG emission reduction target for 2030, as well as several sectoral targets. According to EU`s regulation [20] the NECPs should be periodically updated to reflect changes of the EU policies, such as the implementation of the European Green Deal and the "Fit for 55" targets. Latvia's NECP states that by 2030 the country will achieve a 65 % reduction in total GHGs emissions without LULUCF relative to 1990 level, reduction of GHG emissions in non–ETS sectors by 6 %, compared to 2005 level [2]. In consequence with the updating of the NECP in 2023, higher targets are likely to be set. Among other, NECP [2] states, that land management, arable and livestock farming must be carried out in a sustainable way, taking into account climate, environmental protection, economy and social aspects, as well as high productivity in agriculture through efficient use of bio resources. Resource efficiency and reduction of GHG emissions in agriculture have been highlighted as key area for action. The following measures as main actions and activities for agriculture emission reduction has been identified:

- Efficient use of fertilisers and improvement of the manure management system,
- Organic dairy stock farming (emission-reducing dairy farming),
- Improving fertility of soils,
- Improvement of animal nutrition,
- Improving CO_2 removals in forest stands,
- Improving the quality of soils,
- Promoting and supporting the installation of green fallow before winter crops,
- Support the development of innovative technologies and solutions to promote resource efficiency, GHG emissions reduction/CO_2 deployment in agricultural activities.

For each of the measure's outcomes of action, responsible institution for implementation and financial sources are determined that ensures practical perspective to the implementation.

In the NECP essential measures related to other sectors are also highlighted, for example, promoting the use of negative emission technologies in electricity generation and by introducing additional measures to promote biogas production, 'Greening' of the tax system and improvement of the attractiveness of energy efficiency and Renewable energy technologies as well as education, public information and raising of awareness.

Yet an effective movement towards climate smart and sustainable agriculture in the framework of climate change mitigation perspective within the given policy framework cannot be sustained without sector specific policy and incentives planning. CAP is not only one of the oldest EU`s policies but also the most powerful tool in this regard and it`s modernised and simplified approach of 2018 and is based on a more flexible performance yet result-based approach while increasing EU`s and national sustainability endeavours.

Latvia's CAP draft Strategic plan for 2023–2027 prepared by Ministry of Agriculture is submitted to EC on 18 January 2022 [21]. The draft Strategic Plan supports the GHG reduction measures for the NECP implementation and it: promotes the efficient use of fertilizers, improves soil fertility and quality, improves animal nutrition, improve manure management by supporting investment in farms, further biogas production farm needs, improve pasture management by supporting the necessary investments in agricultural holdings by such as rotary grazing, contributes to the conservation of CO_2 in the soil, promotes CO_2 sequestration by supporting afforestation.

According to Informative report to Cabinet of Ministers "On the Strategic Plan of the Common Agricultural Policy of Latvia for 2023-2027" prepared by Ministry of Agriculture (approved by Cabinet of Ministers 18.01.2022), 4 % GHG emission reduction in agriculture sector emissions being planned in 2027 [22]. Although current version of the CAP Strategic Plan does not contain information on particular climate change mitigation target for agriculture sector, Informative report to Cabinet of Ministers informs about national ambition that can be considered as specific agriculture sector related target [22]. This could stimulate effective move from action based approach in evaluation of climate change mitigation outcomes to the approach recently communicated by EU [4] – result based model.

A summary of Latvia's GHG targets, including agriculture sector based on national and international legislation for period until 2050 is presented in Table 1.1 [23].

Table 1.1

Overview of Determined and Indicative Latvia's GHG Targets, Including Agriculture Sector

	2013 - 2020	2021- 2030	2021-2030 indicative	2040	2050
Total GHG emission reduction target **without LULUCF** sector (compared to 1990)		**-65 %**		**-85 %**	
Total GHG emissions with LULUCF sector					**Climate neutrality** (non-reducible GHG emissions are offset by removals in the LULUCF sector)
non-ETS GHG emissions (compared to 2005)	**+17 %**	**-6 %**	-17%		
EU ETS GHG emissions (compared to 2005)	**-21 %**	**-43 %**	-55%		
Agriculture sector		**-4 %** (2027)			
LULUCF sector			-644 ktCO_2 eq		

From the information summarized in Table 1.1, it can be concluded that separate GHG reduction target has been set for the agriculture sector for 2027 in the framework of CAP, but there is no separate target for 2030.

It can be concluded that national legislation overall being prepared for the GHG reduction in the agriculture sector. GHG reduction measures have been identified and developed into policy planning documents, but the future challenged lies on their practical implementation at farm level, and only then the results and benefits will be reflected at national level.

Agricultural land is one of the most significant resources in Latvia and occupied approximately 36 % (1.9 million ha) [24] in the latest years of the territory of Latvia. Amount of utilisation of agricultural area for the period 2010–2019 is quite stable (Fig.1.2) [25]. On average, arable land occupies 67 %, meadows and pastures 33 % and permanent crops 0.5 % of utilized agricultural area.

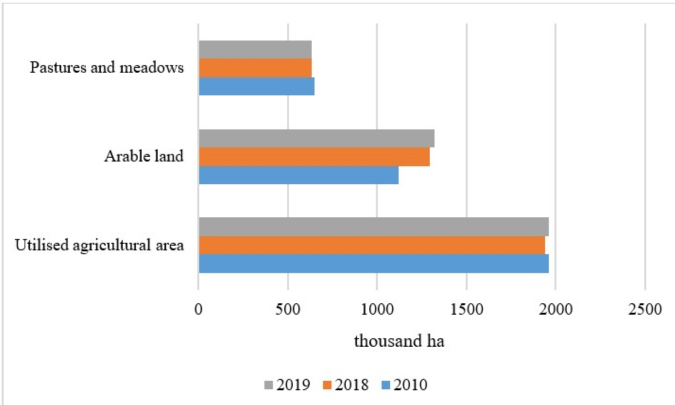

Fig. 1.2. Utilisation of agricultural area, thousand ha [25]

Latvia's climatic conditions and soil fertility are suitable for a variety of agricultural production sectors, including grain, rape and vegetable production. Grain growing is one of the most important agriculture sectors in Latvia, as it provides population with food and livestock - with concentrates. Recently, the use of cereals has become more common also in other sectors, such as energy. According to the information provided by CSB, the highest harvested production of grain was recorded in 2019 – 3.2 million t [25]. The average grain yield per one hectare reached 42.6 ql, which is the second highest grain yield in the history of Latvia. The grain harvest was significantly affected by the increase in share of winter cereals in total cereal land from 35.4 % in 2018 to 58.8 % in 2019. It should be emphasized that use of nitrogen per hectare of sown area increased from 62 kg in 2018 to 64 kg in 2019.

In turn, historically dairy farming is one of the most important branches of agriculture in Latvia, for example, in 2019, 981.4 thousand tons of milk were produced (including goat's milk), which is 1.5 thousand tons or 0.2 % less than in 2018. The decrease in milk yield was influenced by the decrease in the number of dairy cows. The average milk yield from a dairy cow increased by 277 kg or 4.2 %, reaching 6891 kg per year [26]. The Latvian livestock sector has been affected by historical events and the economic situation, but in more recent years cattle, veal, pork and sheep production is increasing.

Local farms are mainly family businesses. Since 2009, the number of large farms has increased, while small farms have been closed, however dairy and other farms in Latvia are characterized by a low herd size in comparison with other European countries [26]. According to latest Agricultural Census 2020, 69 thousand agricultural holdings were registered with average farm size of 28.4 ha (in UAA per holding) in 2020 [25]. Provisional results of the census showed that within 10 years, the number of agricultural holdings has decreased by 17.2 %, but the utilised agricultural land has increased by 9.1 %. However, it was evaluated that permanent employees in agriculture in 2020 were by 13.5 % less than in 2010. It is important to acknowledge comparing the results of the agricultural censuses of 2020, 2010 and

2001, that there is a tendency that the area of the cereal cropland is increasing in agricultural holdings growing cereals and, compared to 2016, in 2020 sown areas of industrial crops per agricultural holding increased on average by 12.6 %. The area under rapeseed have increased significantly on average from 50.2 hectares in 2016 to 58.3 hectares in 2020 in one rapeseed growing agricultural holding [25].

Historical and projected GHG emissions are a key indicator for assessing progress towards climate goals. Therefore, Latvia's GHG inventory and reports on policies, measures and GHG projections (such as Biennial reports) are used for this assessment. Latvia is obliged to prepare and submit these reports to the UNFCCC Secretariat and the European Commission accordingly to the international legislation. The main sources of GHG emissions and methodologies for calculations in the GHG inventory are determined according to the UNFCCC Decision 24/CP.19 [27]. The following sectors are included: energy (including transport sector), IPPU, agriculture, LULUCF and waste.

Latvia has to prepare and submit the GHG emission/removals projections using variety of scenarios, including currently implemented and adopted policies and measures (WEM) and additionally planned policies and measures (WAM) to EC and UNFCCC [10], [28], [29], [30].

Reviewing legislation, guidelines and the report's, author of Thesis came to conclusion that rather complex system is in place for submission of PAMs. Literature review allows to understand main parameters and requirements. It is mentioned examples of single PaMs: unique policy interventions, pursue a well-defined and specific goal, monitoring and evaluation possible, impact can be assessed (ex-ante and ex post), known period of time, task for implementation body. In turn group of PaMs is coordinated set of individual measures [29]. Use of PaM have to be related with the relevant objective [3], following objectives could be used for agriculture sector: improved livestock management, improved animal waste management systems, reduction of fertilizer/manure use on cropland, other activities improving cropland management and activities improving grazing land or grassland management [29]. All of PaM must be selected from using of certain policy implementation types, e.g. Economic, Fiscal, Voluntary, Regulatory, Information, and Education (Table 1.2). Also it is very significant to consider and to analyse the stage of the policy, whether the planning, implemented, or expired stages.

Table 1.2

Types of policy implementation

Implementation type of Policy	**Short description**
Economic	infrastructure programmes, subsidies, investment programmes, feed-in tariffs, loans/grants and trading schemes (e.g. ETS), charges and fees for non-beneficial actions (e.g. waste fees or congestion charges etc.).
Fiscal	includes both increases and decreases in taxes.
Voluntary	agreed between regulators and target group (e.g. automotive farmers).
Regulatory	set binding standards and regulations or permitting systems, includes for instance building regulations, eco-design standards, establishment of permit and inspection procedures.
Information	disseminate information to the general public or specific target groups (labelling, awareness rising, voluntary standards
Education	training programmes, workshops, seminars at all levels

Latvia's GHG emissions and removals by sectors for time period 1990-2019 and structure of total GHG emissions for 2019 [1] are shown in the Fig.1.3 and Fig. 1.4 accordingly.

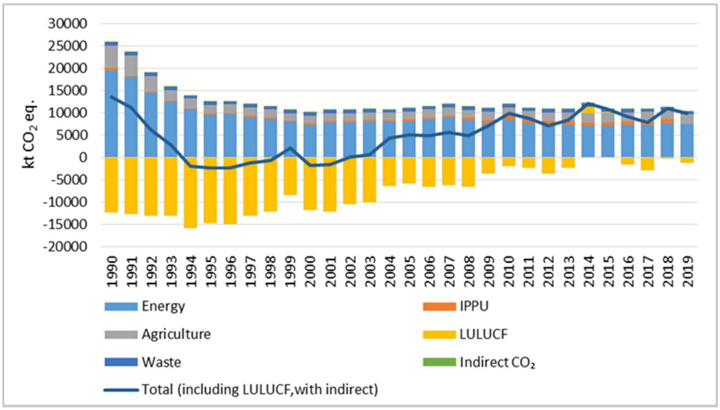

Fig. 1.3. Latvia`s GHG emissions and removals by sectors 1990-2019 (kt CO_2 eq.) [1]

As agriculture sector is the second most significant source of Latvia's GHG emissions, with 19.8 % of total GHG emissions excluding LULUCF in 2019, the Thesis is more focused on this part of emissions.

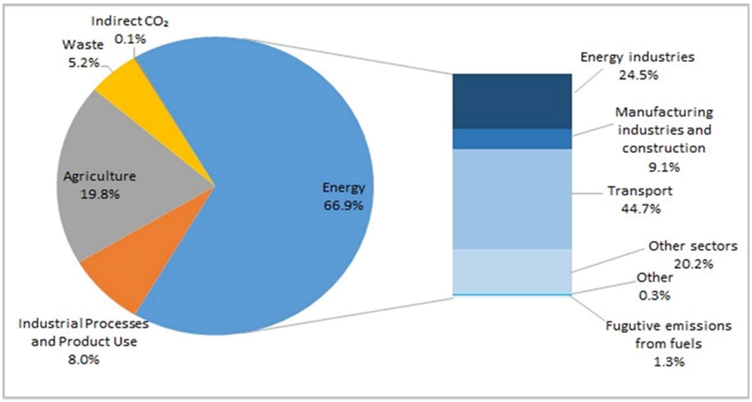

Fig. 1.4. The structure of Latvian GHG emissions in 2019 [1]

The sectors included in the GHG inventory interact with each other. The energy sector is linked to all GHG emitting sectors. In turn agriculture sector's linking in national GHG inventory is shown in the Fig. 1.5 [31]. The agriculture sector is mainly linked to the energy, LULUCF and waste sectors. In future studies, it would be very important to look at the agriculture sector with LULUCF, as these sectors have been planned to be merged after 2030.

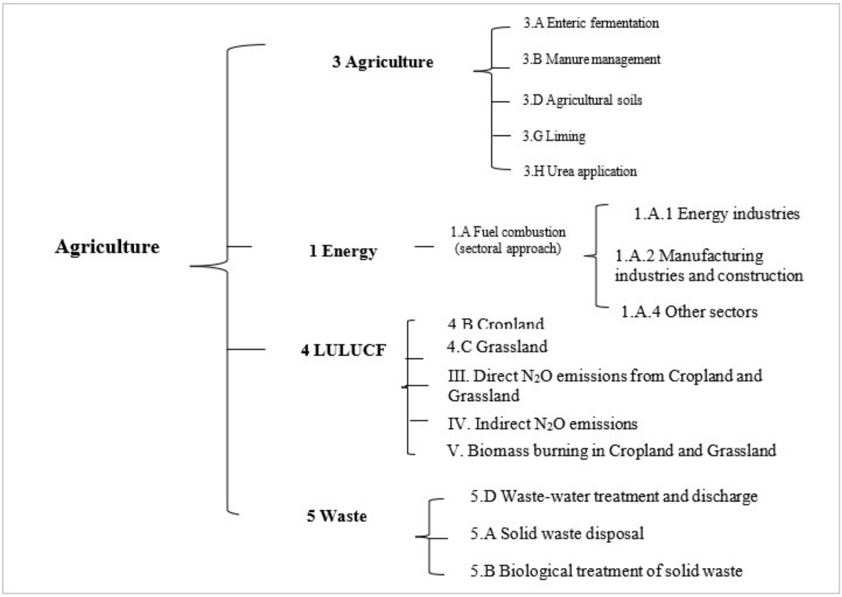

Fig.1.5. Agriculture sector relationship in national GHG inventory [31]

In the agriculture sector, CH_4 and N_2O emissions from enteric fermentation of livestock, manure management, agricultural soils and CO_2 emissions from liming and urea application are calculated. Mainly for the calculation of emissions the 2006 IPCC Guidelines [32], national activity data form CSB, national studies for better characterizing national circumstances for various parameters, for example, manure management systems (MMS) N excretions per head of animal, $Frac_{LEACH-(H)}$, N losses by leaching/runoff [kg N lost from kg N input] are used. MMS distribution is based on national research of Latvia University of Life Sciences and Technologies [33].

In 2019, the largest part of the total agriculture sector emissions (given in kt CO_2 eq.) constitutes N_2O emissions (54.6 %), following CH_4 (42.9 %) and only 2.5 % is CO_2 emissions from liming and urea application (Fig.1.6).

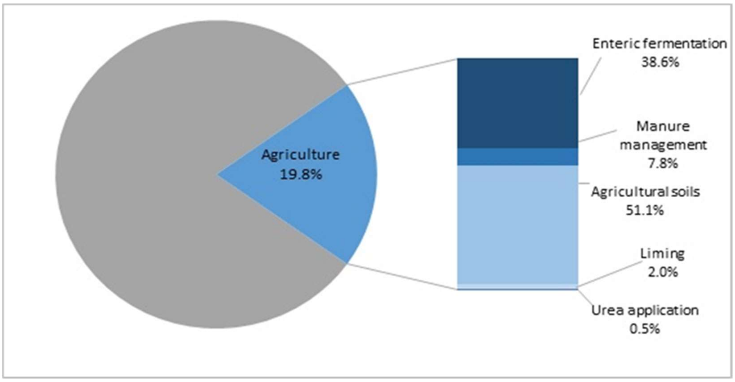

Fig. 1.6. Emissions from the agriculture sector compared to the total emissions in 2019 [1]

Annual emissions from the agriculture sector have reduced approximately by 55.8 % since 1990 due to decrease in agricultural production, however in 2019 emissions increased by 5.0 % compared to 2018 due to the increase of livestock and fertilizer use (see Fig.1.7.). Emissions from agricultural soils were responsible for 51.1 %, enteric fermentation 38.6 %, but manure management created 7.8 % of the total GHG emissions from agriculture in 2019.

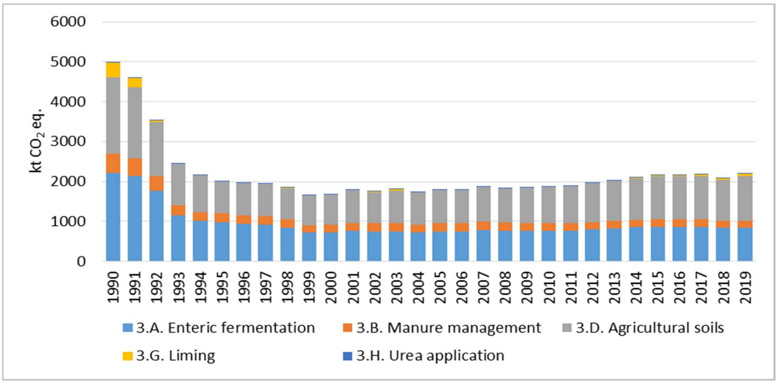

Fig. 1.7. Trend in GHG emissions from agriculture sector in 1990-2019 (kt CO_2 eq.) [1]

According to information provided in National GHG inventory report 2021 the inter-annual fluctuations in emissions observed from the time series were mainly due to the fluctuations in activity data over the years due to changes in the number of animals that were significantly affected by the economic situation in the country, as well as agriculture policy.

Identified key emission categories in agriculture sector for 2019 are provided in the Table 1.3. Key categories characterize significant influence on country's total GHG in terms of the absolute level and help to prioritize improvements for national GHG inventory at sectoral level.

Table 1.3

Key categories of agriculture sector emissions in 2019

Category	Gas
Enteric Fermentation - Cattle	CH_4
Manure Management - Cattle	CH_4
Manure Management - Cattle	N_2O
Indirect emissions from Manure Management	N_2O
Manure Management - Swine	N_2O
Direct emissions from managed soils	N_2O
Indirect Emissions from managed soils	N_2O
Liming	CO_2

As mentioned before the large part of emissions come from soil management where direct and indirect N_2O emissions from managed soils are calculated in following subcategories (1) application of synthetic nitrogen (N) fertilizers, (2) animal manure, (3) compost, (4) sewage sludge and other organic fertilizers, (5) urine and dung N deposited by grazing animals on pasture, range and paddock; (6) N release from crop residues, (7) cultivation of organic soil in croplands and grasslands, (8) N mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils as well as (9) volatilized N from agricultural inputs of N, (10) N from fertilizers and other agricultural inputs that is lost through leaching and run-off.

Analysis of emissions from these categories show that nitrogen input from application of inorganic fertilizers to cropland and grassland was the largest share of total N_2O emissions (34 %), followed by area of cultivated organic soils (24 %), N in crop residues returned to soils (14 %), N input from manure applied to soils (6 %), N excretion on pasture, range and paddock (6 %), Volatilized N from agricultural inputs of N (5 %), N from fertilizers and other agricultural inputs that is lost through leaching and run-off (10 %) and small amount of emissions from other organic N additions applied to soils.

Distribution of total GHG emissions from agricultural soils by sub-categories in 2019 is provided in Fig.1.8 [1].

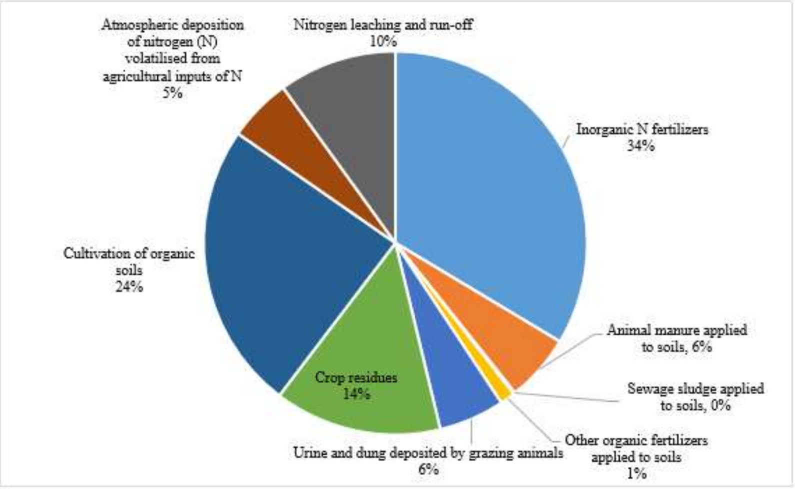

Fig. 1.8. Distribution of total GHG emissions from agricultural soils in 2019 (%) [1]

Emissions from pastures and nitrogen fertilizers have grown the fastest in recent years. This can be explained by the increase in the number of beef cattle in pastures and the increase in sown area. In 2019, emissions of digestate as an organic fertilizer also increased. According to the information of the CSB, in 2019 139.2 thousand tons of mineral fertilizers (expressed as 100 % of nutrients) were used in the sown areas of agricultural crops - by 6.3 % more than in 2018. The increase in the amount of applied mineral fertilizers per hectare (from 108 kg in 2018 to 110 kg in 2019 or by 1.9 % per year) was promoted by the increase in sowing of winter cereals and winter rape - by 21 % and 57 %, respectively [34].

In general, it is very important to pay attention to the reduction of GHGs emissions from agricultural soils and enteric fermentation processes, as these are the main sources of GHGs in the agriculture sector. One of the main emphases of the Thesis is the analysis of reduction measures from agricultural tillage in a sustainable way.

National self-assessment evaluation of determined targets is an essential part of successful policy planning process and thus an important task for relevant decision makers. Therefore, the Ministry of Environmental Protection and Regional Development in cooperation with Ministry of Agriculture, Ministry of Transport, Ministry of Economics, and other ministries annually prepares and submits to the Cabinet of Ministers Informative Report on compliance of the commitments regarding GHG emission reduction and CO_2 removals (Informative report) according to the Law "On Pollution" (2018). In case of detected shortage in successful movement in achieving the defined targets, the report should be supplemented by including additional GHG reduction measures and policies that are in line with the sectoral policy planning documents for the relevant period and are also cost-effective and socio-economically assessed.

Analysing information in previously mentioned reports [1], [23] to clarify path towards determined goals, conclusion can be made, that Latvia will achieve its objectives set for 2013–2020. It is also worth emphasising that so far Latvia has a national target of limiting its emission growth to 17 % above the 2005 level by 2020 for non–ETS sectors (including agriculture sector) that is covered by the EU effort sharing legislation. The Effort Sharing Decision (ESD) determines Latvia's annual emission targets from 9260.06 kt CO_2 eq. in 2013 to 9991.83 kt CO_2 eq. in 2020 [35].

Based on the 2021 Report on policies, measures and GHG projections submitted to the EC [36], Latvia's GHG emissions in agriculture sector will increase slightly over time, with existing measures (WEM) reaching 2867 kt CO_2 eq. level or with additional measures (WAM) 2638 kt CO_2 eq. in 2040. Thus, N_2O emissions from soil and CH_4 emissions from manure management are projected to grow by 8.7 % in 2030 compared to 2018 (Fig.1.9).

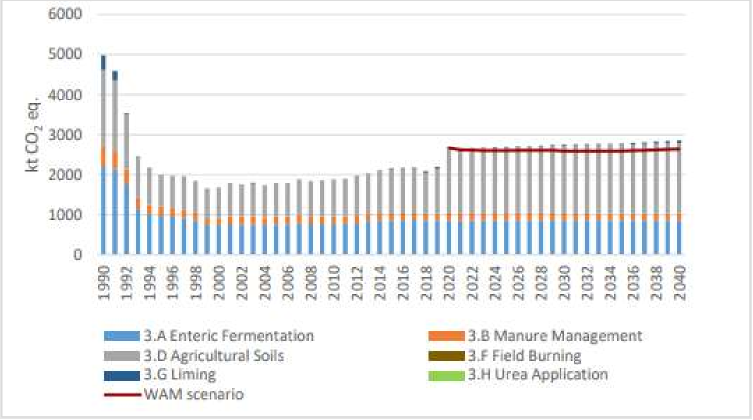

Fig. 1.9. Latvia's historical agriculture emissions projections by source category [1], [36]

Decrease of number of cattle is projected, nevertheless, increase of dairy cattle productivity will lead to increase of gross energy intake and therefore increase of CH_4 emissions from enteric fermentation per dairy cow is planned.

As it can be seen in Fig. 1.9, despite many PaMs, the projected emissions show growing tendency mainly due to increased production. Most of the measures focus on soil and nutrient management (12 implemented and 8 planned PaMs). However, these measures have little effect on projected GHG emissions from agricultural soils, as emissions will continue to increase.

The abovementioned analysis allows reach the conclusion that there are different GHG mitigation measures in place in Latvia's agricultural sector, but the measures of specific result indicators are not set, thus hampering the full potential of climate change mitigation. Comprehensive development on a state scale result-based indicator system establishment for agriculture sector could optimize these trends and stimulate sustainable approaches. According to the report [37] the existing PAMs are related to the implementation of the Nitrate Directive, renewable energy sources directive, and CAP. Planed policies mainly focus on crop/soil management and nutrient management, but unfortunately these measures have a small effect on projected GHG emissions from agricultural soils, as emissions are projected to continue growth. It must, therefore, be concluded that there is a lack of effective measures, and further work on GHG reduction in the agriculture sector is crucially important at all levels - farm, sectoral, and state, to move towards result-based agriculture and climate targets.

1.2. Concept of the result-based agriculture sector

The literature review is prepared sequentially, considering the tasks set in the Thesis. As a result of the analysis of the scientific literature about the concept of the result-based approaches in agriculture sector, several similar views are provided. Janus H., and Holzapfel S., emphasizes three essential elements of result-based approaches [38]:

- choosing measurable results,
- establishment of a payment and verification mechanism,
- providing support to a stimulated participant.

These studies indicate that the result-based approaches have the potential to promote innovation in agriculture and they can play a significant role in increasing food security. Although it was highlighted that there are additional challenges for implementation of result-based approaches, for example outcomes could be floating and affected by different conditions (such as weather). Several decisions must be taken into account when choosing results. Janus, H. concludes that to meet the criterion, the results must always be based on the country's own development strategy and priorities [39]. It is also important to choose the level of the selected result. According to O'Brien and Kanbur [40] outcome – level indicators promote innovation and are more suitable under complex conditions as they only indicate the result, but not the road to reach it. Agriculture sector is very complex, and it is difficult to evaluate and to direct which agricultural innovation is most useful on a case-by-case basis. Therefore Birdsall et al. [41] point out that payments linking to outcome indicators has advantages and experimentation is possible. In turn, Gelb & Hashmi indicate that payments may be made on a pro rata basis or conditional reaching the threshold level [42]. The main requirement for determining the right incentives is that the results are easily measurable, and that the quality of the data is high. Keijzer & Janus emphasizes if result-based programmes are planned, decisions have to be made involving donors in planning, implementation, monitoring as well as in supply of technical support [43]. In addition, the existing theoretical literature suggests that the result-based schemes could be more cost-effective than activity-based schemes [44].

According to the result-based approach [45] newly introduced and emphasized by EU`s communication on Sustainable Carbon Cycles [4] and related documents [46], [47], it requires a direct link between the results achieved (GHG emissions avoided or decreased) and the payments received by farmers. It differs from the best known activity-based schemes, in which the farmer is paid according to very specific agricultural practices or technologies selected for climate change mitigation purposes. In a result-based approach, the payment is closely linked with the quantifiable indicators of the climate benefits provided, regardless of the exact agricultural practices used. It is pointed out [46], [47] that result based impetus offer a number of advantages over action-based impetus such as a more targeted use of relevant resources to achieve the determined climate goal and a greater degree of flexibility for land managers. EU encourages [4] it`s Member States to explore the result-based business model concept and widely implement it considering ambitious climate neutrality target to be achieved by 2050. It is emphasized that sustainable and climate-resilient carbon cycles could be developed in following main phases to achieve such ambitious goals: decrease reliance on carbon, recycle carbon from waste streams, there is a need to improve carbon capture and store solutions [46], [47]. Thinking more broadly, the concept of the result-based agriculture sector is related to sustainability and smart agriculture principles [46], [47], therefore it is essential to deeper analyse the assessment of eco-efficiency at different levels (farm, state), indicators for GHG mitigation possibility, and carbon balance analysis at farm level, to rank bioresources for biogas production at technology and sectoral level, and GHG mitigation measures linking to climate smart and sustainable agricultural practices.

In general, eco-efficiency concept is based on the production of products with higher added value and less impact on the environment. As it is stated by Koskela and Vehmas, eco-efficiency definitions can be presented in five groups [48]. The first group of definitions refers to the expression "more from less", then secondly and thirdly eco-efficiency is considered as the ratio between economic and environmental output. More specifically, the second group emphasizes the emphasis on productiveness: the production of additional value added with less impact on the environment. The fourth group describes eco-efficiency as a control strategy, but the fifth group of the definitions provides more specific guidance of control strategy in the enterprise level for improving eco-efficiency. The main concept of the eco-efficiency is to help companies and governments to become more sustainable [49]. There are three types of methods for measuring eco-efficiency: first the single-ratio model of environmental impact/economic output. The model accepts and combines environmental impacts in one account though life cycle analysis. This single-ratio model is used to analyse the efficiency of products and technologies, as well as is making it easy to understand it. Secondly, replacement of the numerator with other mixed indicators, such as ecological footprint, energy and material flow analysis indicators. This method can be used by evaluating the environmental performance of the system. Thirdly, efficiency assessed by models such as the Range Adjusted Measure model can be used. These models provide and explain advisable and unacceptable outputs in the process of production [50]. A wide range of methods for assessment of eco-efficiency, for example, Delphi method [51], Data envelopment analysis (DEA) [52], Life Cycle Assessment (LCA) [53] jointly with Life Cost Cycle (LCC) [54] analysis and others are described in literature [55]. It is essential to analyse availability of the activity data in both farm and national level to apply these methods for assessment of eco-efficiency. Different kinds of information are available to get insights into ways to measure the impact on environment and climate. There are two substantial questions to be considered for measuring eco-efficiency − how to measure and what kind of possible indicators can be used for measurements.

Examples of environmental, climate and economic performance measurement indicators, which were mentioned in the literature are, summarized below in Table 1.4 [56].

Table 1.4

Environmental and Economic Performance Measurement Indicators for Agriculture Sector

Environmental and economic performance	Indicators
Inputs for the production	Water use, thsd m^3 Energy use or consumption, GJ/TJ Biogas, TJ Raw material consumption, thsd tonnes Land use, thsd. hectares
Outputs as emissions groups	Total GHG emissions from agriculture sector and sub-sectors (without LULUCF), kt or kt CO_2 eq. Total GHG emissions from agriculture sector and sub-sectors (with LULUCF), kt or kt CO_2 eq. CO_2 emissions kt or kt CO_2 eq., N_2O emissions kt or kt CO_2 eq., CH_4 emissions from agriculture sector and sub-sectors kt or kt CO_2 eq. Emissions to water, tonnes Emissions air, tonnes, kt
Environmental impact	Climate change Biodiversity Smell Use of synthetic fertilizers, kt nitrogen Organic soils, ha Fossil fuels, GJ/TJ
Economic indicators	Gross domestic product, thsd. EURO/% Employees, thsd Value added, milj EURO Amount of production, kt/thsd tons
Resource use intensity	Water intensity, m^3/GDP Energy intensity, TJ/GDP Land use intensity, thsd. hectares/GDP
Environmental/Climate impact intensity	Total GHG intensity, kt CO_2 eq./GDP GHG intensity, kg CO_2 eq./kg product CO_2 intensity, kt CO_2 eq./GDP CH_4 intensity, kt CO_2 eq./GDP N_2O intensity, kt CO_2 eq./GDP

One of the main policy directions set out in the current policy planning documents to achieve the climate targets is promotion of the production of biogas [2],[57].

Production of biogas using bioresources of agricultural origin plays an important role in Europe’s energy transition to sustainability and a climate-neutral economy [58], [59] due to the possibilities to use it for different purposes – transportation fuel, heat, and electricity generation

[60]. The transition to clean energy has already proven its role of modernizing the EU's economy, promoting sustainable economic growth and prosperity, as well as improving the environment, creating new jobs and delivering benefits for citizens [61].

The biogas production process integrates production [62], processing and recycling of degradable by-products [63]. Not only does the biogas produced by anaerobic digestion prevent GHG emissions and produce renewable energy, but it also provides the production of processed fertilizers, improving nutrient self-sufficiency in agriculture sector [64]. The productivity of a biogas plant depends on different aspects, like the type of biomass [65], [67], digestion [68], [69], availability of biomass, impurities that may harm microorganisms [70] and lignin content [71].

According to Ugwu et.al., the most important element of the biogas production system is the choice of a substrate, because by knowing the composition of biomass, it is possible to predict the yield of biogas and its ratio of methane [72]. Almost any organic material can be used for the biogas production, for example, paper, grass, animal waste, domestic or manufacturing sewage, food waste, agricultural products [72], whereas finding new sources of renewable energy production is a global issue [73], [74]. However, at the same time specially grown substrates are being rejected for the production of biogas [75].

One of the substrates being rejected is the use of maize because of differences of opinion on its impact on the environment [75], even though maize biogas yields and characteristics are far superior to other crops for biogas production [76], [77]. The usage of some substrates like maize due to controversy of food deficit has been increasingly denounced in the last years and there is currently an active discussion about future subsidies to biogas producers depending on the substrate used.

Not only does maize have a high carbon fixation and assimilation capacity [78], but it can also be grown worldwide due to its high photosynthesis and resource utilization [79], even in conditions of drought, high temperatures and lack of various nutrients [80]. In addition, in the process of anaerobic digestion it is very important to use co-digestion that allows to increase the productivity of produced biogas from 25 % to 400 % over mono-digestion [81]–[82]. Co-digestion is often used for the very reason that the optimal carbon-nitrogen ratio on biogas production is in the rage of 20:1 to 30:1, but in general, manure has very low carbon ratio and it is important to mix it with other substrates that are carbon-rich like maize to increase the biogas yield. In Thesis, a carbon balance was developed and carried out to objectively quantify naturally or anthropogenically added or removed carbon dioxide from the atmosphere in order to determine the environmental impact of biogas production from specially grown substrates, in this case - maize silage. Although many authors have acknowledged that, when analyzing biomass life cycle, the range of results is quite wide [83] due to the differences of various factors and system boundaries [84], therefore it is considered to be the best method for calculating GHG balance [85].

Given that around 6 million tons of agricultural waste is produced in the world yearly and the emphasis on pathways and strategic priorities for transition to a net-zero GHG emission economy, there is a promising future for the development of biogas production, especially for upgraded biogas to biomethane, that is flexible both, in use and storage and because of its production from agricultural, industrial waste and sewage sludge protects soil, air and water from pollution [86-87]. Not only does biogas produced by anaerobic digestion prevent GHG emissions and produce renewable energy from waste, but it also provides for the production of processed fertilizers, improving nutrient self-sufficiency in the agriculture sector [88]. The biogas production process is an environmental technology that integrates production, processing and recycling of degradable by-products [89]. In 2014 there were 54 biogas plants operating in Latvia with a total capacity of 54.92 MW (3.1 PJ) and out of those 54 biogas plants, 44 used agricultural waste, 7 used municipal waste in landfills, but only 3 used domestic or industrial sewage and residues from food production (industrial waste) [90]. Consumption of biogas produced in 2017 increased to 80.73 MW (3.9 PJ) since 2014 [91], reaching a 25.81 % increase of biogas production [93]. Different types of manure present variation in organic composition and dry matter content (1.5–30.0 %), which affects the biogas produced. The yield of different raw materials is shown in the Table 1.5 [93]. The most commonly used substrate with manure for co-digestion is maize silage and one of the reasons comparing the biogas yield of maize silage with the biogas yield of liquid cattle manure, the biogas yield from maize silage is 8.08 times higher [94].

Table 1.5

Yield of various raw materials [93]

	Yield of methane, %	**Yield of biogas, m^3/t**
Cattle manure (liquid)	60	25
Cattle manure	60	45
Pig manure (liquid)	65	28
Pig manure	60	60
Poultry manure	60	80
Maize silage	52	202
Grass silage	52	172
Organic waste	61	100

The use of lignocellulosic substrates after pre-treatment [95] for biogas production should be evaluated. Given that the use of maize and rapeseed silage in biogas production will no longer be acceptable, it is necessary to find new raw materials that occurs as a result of other processes as waste. Considering that a half of Latvia's territory is covered by forests in 2016, and 36.5 % of Latvia's territory is covered by agricultural lands, Latvia has a big potential to use harvesting and agricultural crop residues and waste, that have high levels of lignin in their content [96].

Grasslands have a variety of functions in agriculture – not only are they are the main source of feed for livestock, but overall, they provide benefits such as carbon storage and soil protection from erosion, groundwater formation and habitat formation in diverse landscapes and natural foundations [97]. Although grasslands can be used in the production of lignocellulosic bioethanol, synthetic natural gas or synthetic biofuels, according to the Green Biorefineries concept, the sustainable use of grass biomass is directly linked to the production of biogas [98]. Knowing the feasibility of successful processing of such raw materials and their practical application, it is understandable that they are potential raw materials also in the agricultural conditions of Latvia.

Anaerobic digestion has been mainly implemented for the management of animal manure, organic and agricultural waste, sewage sludge, plant green mass etc. [99]. Theoretically it is possible to use forest and wood processing waste and peat [100]. Manure is the most suitable material for biogas production. The easiest way to get biogas is from cattle manure. The dry matter content of the manure depends on the used amount of litter, moreover if a lot of washing water is used, the manure is watery [101]. Pig manure is also suitable for biogas production, because it contains not only manure, but also feed residue and litter. Poultry manure is suitable for biogas production also, but there tends to be sand, and feathers mixed in the manure, which can cause problems, when specially adopted pumps are not used. Because of the high concentration of nitrogen, it is advisable to mix poultry manure with cattle manure.

If biogas is utilized in a technologically efficient way and sector, it can not only make an economic contribution, but also reduce emissions [101], however inefficient use can affect not only the economy, but also the environment and food.

Although there are various forms of support for biogas producers in Europe and elsewhere in the world, the legislation in Latvia is so unstable and different that entrepreneurs are afraid to invest in biogas or treatment plants, therefore, even though the number of stations should increase, the trend is that they decrease every year [102]. Given that, in theory, a biogas plant must be able to operate economically independently, even without public subsidies, in parallel with its main task of reducing emissions, the main challenge is to provide practically valuable material with technological information on how to achieve it with maximum efficiency.

However, focus of this Thesis is on agricultural biogas that can be used for two purposes in the energy sector: (a) combusted in CHP, as well as electricity used for road transport; (b) purified to biomethane used for road transport (Fig.1.10).

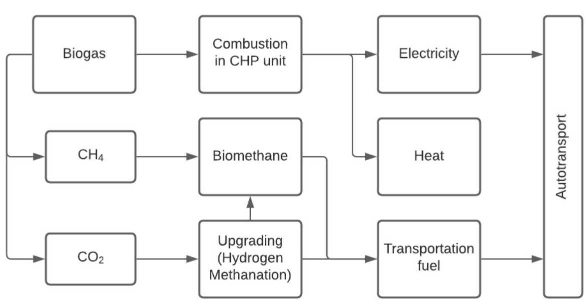

Fig. 1.10. Biogas application

According to the IPCC Synthesis report 2015 [103], the most profitable mitigation possibility is cropland and grazing land management as well as organic soils renewal in agriculture. Efficient mitigation and adaptation are related to implementation of policies and measures at several levels, including avoidance of use of less labor-intensive technologies in the agriculture sector.

As emphasized above mitigation measures are essential element for GHG emission reduction in agriculture sector. The roadmap for the future is to work in more sustainable way taking into account also adaptation to climate change and GHG emission decrease that together make up climate smart agriculture objectives. Moving towards sustainable development of the agriculture sector in a light of growing climate change impacts and mitigation and adaption commitments taken at different levels reveals the need for integrative sustainability based approach and CSA concept is one of the principal paths to be considered.

In 2009, for the first time the CSA idea was initiated [104]. The term was reflected at the Hague Conference on Agriculture, Food Security and Climate Change by the Food and Agriculture Organization of the United Nations (FAO) in 2010 [105]. According to the FAO often used definition of CSA agriculture is that increases productivity in a sustainable way, increases resistant, decreases GHG, and increases the achievement of national food security and goals of development [106]. Lipper et al. also noted that definition and essential aim of CSA is the development and security of food [106] and productivity, adaptation, mitigation are pointed out as three interconnected activities to reach this aim. Lipper et al. [106] also say that CSA could be explained as an approach for reorienting and transforming agricultural development taking into account climate change. However, A. Amin et al. [107] stated that CSA can be determined as agricultural productivity growing in a sustainable way, building and adapting resilience to climate change, GHG emission reduction as well as that it is a possibility to increase the policy, technical, and investment on the environment to get continual agricultural growth for food protection due to change of climate. As it is written by L. Lipper and D. Zilberman [108], CSA aims to provide comprehensive appropriate principles of agricultural management for food security due to climate change that would ensure a foundation upon which to build policy support as well as recommendations of organizations. FAO emphasizes three objectives of CSA (Fig. 1.11) [109], which can contribute to achieve the Sustainable Development goals.

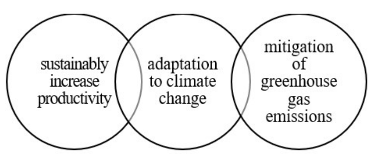

Fig.1.11. Objectives of climate smart agriculture

It is recognized that to reach the objectives set in Fig. 1, agricultural production and food systems will need to use natural resources and other inputs in a more efficient way and become more resilient to change [110].

CSA is mentioned in literature as an integrated approach to better adapt crops and livestock to climate change as well as agricultural methods, and thus reduce GHG emissions, considering technological and environmental availability factors [111] at the same time taking into consideration the growing population for which there needs to be a guarantee in food security [112]. Thus, the emphasis is not simply on sustainable agriculture, but also on increasing agricultural productivity. The CSA is consistent with the vision of FAO and also supports the aim to turn agriculture into a more sustainable and efficient sector [106].

Smart agriculture is directed towards guiding the land supply and depending on its status, focusing on suitable growing parameters, such as material content, fertilizer, moisture – to ensure production of the appropriate crop that is in demand. The ways precision farming is implemented depends on the software used by sustainable entrepreneurs [113]. In the management of agriculture, reasonable intensification is necessary [114] and CSA is the solution [115]. Challenges related to climate change in the agriculture sector ask for acceptance of innovative methods in order to increase resilience, decrease influence, while supporting the productivity of the farm [116]. This set of activities has been also widely indicated by the FAO (2010).

Many policy instruments might be implemented for CSA practices adoption in agriculture sector, for example, regulatory and economic instruments (taxes, compensations) as well as on information-based instruments (e.g. Certification and labelling) [117]. The EU encourages Member States to include CSA principles in their Strategic Plans of Common Agriculture Policies through economic instruments.

The main reason for measuring GHG emissions is to contribute the management and decrease of these emissions. GHG emission analysis plays a significant role in measuring company's (farms), sectoral, sub-sectoral and national level emissions. Such analysis makes it possible to identify the main areas of GHG emissions at each of the above levels, thus working on more effective GHG reduction practices, as well as demonstrating the commitment of customers, government and society to sustainable, environmental and climate-friendly practices. According to Smith et al., [118] many farming methods have the potential to reduce GHG emissions. In the context of GHG reduction in the agriculture sector, researchers see three lines of action: firstly, the use of efficient GHG reduction methods, secondly, the reduction of carbon sequestration in the soil, and thirdly, the use of climate-friendly practices for the production of renewable energy such as biogas, bioethanol or biodiesel. With regard to the reduction of GHG emissions in the agriculture sector, one of the scientifically recognized approaches [119] is the classification of measures into 4 different categories: agronomy (nitrogen balance, leguminous, cover crops, conservation agriculture) animal husbandry (manure storage and spreading, biogas) energy (biomass, photovoltaic, fuel an electricity reduction) and agri-environmental measures. Asgedoms et al. classify reduction measures related to crop and animal production as well as manure/soil management [120].

Besides, nationally comprehensive studies to identify the most appropriate GHG mitigation measures for local circumstances were done by the Latvia University of Life Sciences and Technologies - researchers selected 17 GHG reduction measures best fitting for Latvian conditions and analysed them from the perspectives of farm size and structure, as well as cost-benefit analysis was performed to develop proposal for inclusion of the selected and examined measures into national policy documents [121]. The research outcome has served as a basis for current development of national legislation for reduction Latvia's GHG emissions in the sector of agriculture, including the measure targeted approach, to support of biogas production.

As stated by Popluga D., measures focused on improving management practices, including environmental benefits such as GHG emission reduction are known as beneficial management practices (BMP). BMPs globally are recognized as one of the most efficient approaches for mitigation of GHG emissions. However, since these practices are diverse the use of them depends on a state policy, and support instruments, climatic, geographic conditions as well as agricultural practices [122-123]. Considering the importance of the sector in national GHG balance, national studies on GHG mitigation for agriculture are ongoing and different methods of analysis are tested.

1.3. Summary of literature review: blind spots in agriculture sector

Complexity and socio-economic importance of the agriculture sector for decades has determined specific emphasis on multilevel and structured scientific research in the field of GHG mitigation, adaptation and above all finding the climate smart, result-based and thus inclusive pathways to further sustainable development of the sector. Wide variety of studies and approaches discussed above allow us to understand not only the existing scientific research areas of debate, but also uncovering the array of blind spots to be investigated to ensure more stable move on result-based agriculture sector development and climate change mitigation targets achievement.

The specific nature of the agriculture sector and it`s complex ties to other sectors of the economy sets acknowledgement that studies must be continued and there are still number of elusive research angles left. Therefore, the following study areas are identified and suggested for further research concerning move towards the result-based agriculture in the light of climate neutrality:

- methods to detect horizontally correlations that appear to be relevant to possible transition towards result-based agriculture sector and climate targets,
- an assessment of the eco-efficiency of the agriculture sector, taking into account various indicators,
- indicators for GHG mitigation possibility in agriculture sector using GHG emission reduction model,
- carbon balance analysis for assessment of the impact of biogas production from maize and MCDA TOPSIS use for ranking bioresources for biogas production as promotion of biogas production is mentioned as one of the measures for GHG mitigation in agriculture,
- MCDA TOPSIS together with the use of the Delphi approach to identify the most effective GHG emission reduction measures,
- proposition of the decision-making analysis tool for result-based measures.

2. METHODOLOGY

According to the structure and tasks of the dissertation the methodology will be examined sequentially: (I) regression analysis; (II) theory-based analysis; (III) carbon balance analysis; (IV) multi criteria decision analysis TOPSIS; (V) combination of the Delphi approach/MCDA TOPSIS; and (VI) combination of comparative analysis/MCDA TOPSIS.

2.1. Regression analysis

Regression analysis is a statistical method of relationships between a dependent variable and independent variables. The tasks of regression analysis are [124]:

- to determine the statistical relationships of an independent and dependent random variables quantitative parameters of closeness,
- to determine the coefficients of the regression equation (mathematical model).

The regression analysis is used to identify the strength of the effect that the independent variable has on a dependent variable. Regression analysis also is used to predict trends of dependent values. Regression analysis include linear, multiple linear and nonlinear regression.

The most used methods are linear and multiple linear. Regression analysis determines the precise quantitative parameters of random magnitude changes, that is, determines the significance of the stochastic connection with functional relations. The results of the regression analysis are correct if the necessary rules of application are observed [125]. There are many rules, and it is not always possible to follow them all in practice. The main conditions of applying a regression analysis are several. Application of the regression analysis is correct in cases where the dependent variable magnitude (reduction of GHG emissions) follows the law of normal distribution. This requirement is not in effect with respect to independent variable magnitudes. This means that analysis begins with determining the distribution of dependent variable magnitudes and analysis can be continued if the distribution adheres to the law of normal distribution.

Regression analysis starts with determining the distribution of dependent variables. It must comply with the rules of normal distribution so that it can be used in the subsequent breakdown [126]. The interlink closeness (correlation) between independent and dependent case variables can be assessed by means of a correlation factor. The Pearson equation (Eq. 2.1) [127] could be used for the calculation of a single factor mathematical model:

$$\mathrm{r} = \frac{\sum_{i=1}^{m}(xi- \ )(yi-y)}{SxSy(m-1)}, \tag{2.1}$$

where x_i, y_i – the independent quantities and the corresponding pairs of dependent quantities,

x, y - arithmetic mean values of independent and dependent quantities,

S_x, S_y - the size of the random variance.

In case of multifactor correlation, the multifactor correlation coefficient R is used. The coefficient is not statistically interpretable but is determined and used as an indirect regression the usefulness of the equation [128].

In case of nonlinear regression, a correlation ratio is used instead of a correlation coefficient. The correlation ratio in nonlinear regression has the same meaning as the coefficient in linear in regression - it describes the grouping of results around a nonlinear regression line. Correlations the value of the coefficient can vary from –1 to +1. If the correlation coefficient is equal to 0 or close to it, this indicates that there is no correlation between the variables, but coefficient values equal to –1 or +1 indicate a functional relationship between independent and dependent variables. It should be noted that correlations are usually calculated for statistical data processing coefficient squared. Square of the correlation coefficient R^2 indicates the regression under consideration characterization of the equation taking into account the change in the dependent random variables [129]. Multivariate regression analysis could be performed to obtain a mathematical model that characterizes dependent variable using two or more independent variables. With the coefficients of the linear regression equation can be determined by means of regression analysis statistical analysis of the results and the regression equation (Eq. 2.2) could be determined from the initial data:

$$y = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_n x_n \quad (2.2)$$

where

y – dependent variable,

b_0 – free member of regression,

$b_1, \ldots, b_n$ – regression coefficients,

$x_1, \ldots, x_n$ - independent variables.

The coefficient of the regression equations (Eq. 2.2) $b_0, \ldots,$ bn can be used to estimate the statistical significance t criterion, which has a Student's distribution with degrees of freedom (Eq. 2.3).

$$f = m - (n + 1) \quad (2.3)$$

where

m – the amount of data relevant for the characteristic analysis,

n – the independent variable number in the regression equation.

To perform the evaluation, each coefficient with a computer program calculated t criterion is compared with the value of t_{tab} found in the Student's distribution tables, respectively the degrees of freedom P and f of the chosen level of significance. Frequent processing of energy-related data a significance level of $P = 0.05$ is used, which corresponds to a probability of $1 - P = 0.95$. If the rule for the weighting to be evaluated is $| t | > t_{tab}$, then it is important and should be left out in the regression equation. Otherwise, this equation must be discarded and analysis must be repeated until all remaining coefficients are statistically significant. This whole procedure is performed with the aforesaid computer program. The estimation is performed by analysis of variance using Fisher's criterion F (Eq. 2.4). This ratio of the variance of the dependent variable to the balance is considered as part of the activity's dispersion.

$$F(f^1, f^2) = \frac{Sy^2(f_1)}{Satl^2(f_2)}, \quad (2.4)$$

where

$S_y^2\ (f_1)$ - variance of the dependent variable y,

$S_{atl}^2 (f_2)$ – residual dispersion.

The balance is determined as a function of the dependent variable and the regression equation the difference between the calculated value y_i and y_i^{apr}. The degrees of freedom f_1 and f_2 are calculated by the equations (Eq. 2.5, 2.6):

$$f_1 = m - 1 \quad (2.5)$$

$$f_2 = m - 1 \quad (2.6)$$

If the value of the F criteria is greater than the critical value determined from the F distribution tables, taking into account the degrees of freedom f_1 and f_2 as well as the significance level P, this means that the equation describes the data to be analyzed and can be used for further analysis.

For achieving the Task No 1 of the Thesis in general it is considered of four main steps which characterize eco-efficiency performance process (Fig.2.1). The analysis of eco-efficiency indicators was done step by step.

Fig.2.1. Eco-efficiency performance process

Firstly, collection of statistical data was done to select appropriate indicators and then analysis of absolute values of indicators was carried out for data processing and analysis.

As an economic indicator of the gross domestic product (GDP) of the sector, and for measuring of the environmental indicators – emissions were used. The selection of indicators depends on the ways they will be used. It is significant to set generally applicable indicators that can be used by all interested groups (for example, farms, government, other institutions) and therefore clearly described measurement methods are needed. Based on the available literature, many of indicators were highlighted (for example, inputs for the production, energy intensity (MJ/GDP), land use (thousand hectares/GDP), water intensity (m^3/GDP) and environmental impact: climate change, biodiversity, smell) (Table 1).

For detailed analysis of eco-efficiency only energy use, inputs for production, production of agricultural products, emission groups (GHG emissions, emissions to water and air) and environmental impact on climate change were used.

Regression analysis was used for evaluation of the relationship between GHG emissions and production of agricultural products or other parameters.

Firstly, the regression analysis is used to identify the strength of effect that the independent variable has on a dependent variable.

To calculate linear regression, the following equation (Eq. 2.7) was used:

$$y = a + bx \tag{2.7}$$

where

x – the explanatory variable,

y – the dependent variable.

The slope of the line is b, and a is the intercept (the value of y when x = 0). The regression analysis was conducted in this order:

1. the law of distribution of the dependent variable magnitude in the reduction of GHG emissions was verified,
2. a regression equation was determined, using the least squares method,
3. statistical analysis of results obtained was conducted.

When selecting the model for the analysis, another important consideration is the model fitting and estimation how independent variable explains variance of the model (typically expressed as R^2). With the aid of correlation coefficients, this study evaluates how precise mathematical models describing correlation proximity are. It is commonly accepted that correlation is good if coefficients are from 0.8 to 0.9. It must be noted that computer programs for statistical analysis usually calculate the square of the correlation coefficient. If the R^2 value is multiplied by 100, then a magnitude (as a percentage) is acquired, which describes the changes in dependent variable magnitudes gained from empirical equations to be analysed. For example, $R^2 = 0.9$ indicates that the equation of the regression to be examined describes 90 % of changes dependent random magnitudes.

2.2. Theory-based evaluation

The part of the research focusing on the agriculture sector GHG emission mitigation possibilities using the theory-based methodology. The main task of theory-based methodology is evaluation of reaching of determined target according to legislation taking into account the selected indicators together with different GHG mitigation measures, and if these determined targets are achieved, then indicators can be added to the indicator list for use in GHG mitigation measures. Then, evaluation of normalization and weighting of the indicators by experts were done, and finally, these indicators for evaluation of GHG emissions mitigation measures were used. To achieve the second objective of this Thesis, analyse of existing indicators based on the literature review is used for evaluation of impacts of agriculture on environment, to propose a tool with a set of indicators for assessment of GHG emissions mitigation measurements, and to assist stakeholders in decision making regarding production of agricultural products with a high added value. The basic methodological framework concept is shown in Fig.2.2.

An indicator is a parameter that, as a data element or combination of data, displays information about the relevant situation and can be used to make assessments of the situation, as well as help to make a decision against a reference point, and can be used as an evaluation function and assess objectives [130]. The indicators do not only show current conditions or trends, but also provide an understanding of how activities affect different dimensions of sustainability - economic, environmental and social [131].

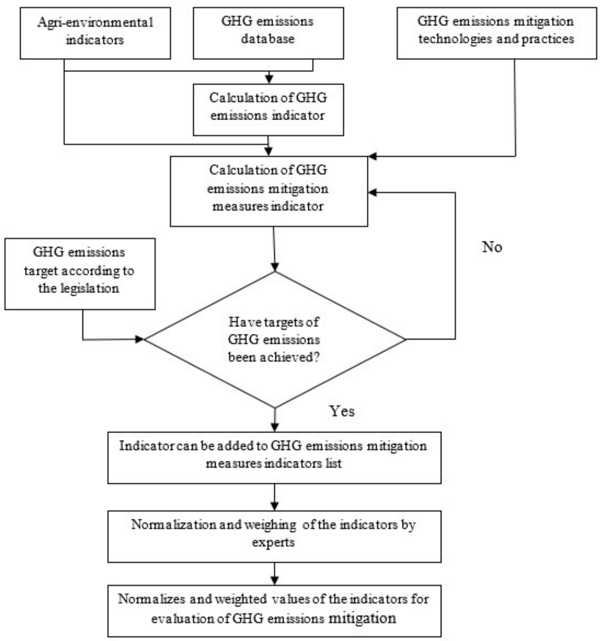

Fig.2.2. Methodological framework of selection and evaluation of indicators for GHG mitigation measures in the agriculture sector

2.3. Carbon balance analysis

A carbon balance analysis based on a life cycle approach was used to assess the overall environmental impact of maize production for biogas production at farm level, which included the following calculations: GHG emissions from maize silage cultivation due to tillage, mineral nitrogen fertilizers and fuel use in heavy machinery (both in the process of growing maize, in the process of preparing the substrate for biogas production, and in the process of incorporating digestate into the soil); emissions collected due to the photosynthesis process; emission leaks from biogas production process; emissions from the use of maize digestate fertilizer; and emissions saved from the mineral fertilizer replacement with digestate.

Specific international standards ensure methodology for calculating carbon emissions, depending on the research aspect (for example for farm, national level). IPCC methodology for GHG emissions calculation is the most used and globally accepted. The IPCC guidelines are used for the preparation of national GHG inventories as well, where with the common and simple methodological approach is possible to evaluate emissions from a human activity which takes place, taking into account coefficients called emission factors (EF) that quantify emissions or removals per unit activity.

Each sector includes separate categories (e.g., agriculture) and sub-categories (e.g., soils). As a result, countries create a total GHG inventory from the sub-category level as this is approach how IPCC methodologies are constructed, and national total emissions calculated by summing up emissions and removals for each gas. According to the UNFCCC Decision 24/CP.19 [27] the 100-year time-horizon global warming potential (GWP) values from the IPCC Forth Assessment Report [101] must be used to report aggregate GHG emissions and removals (expressed in CO_2 equivalents) in GHG inventory.

The IPCC software, including EF for sources and sinks can be used on national level as well as in the individual models. Globally, there are available several databases for EF, among which is the IPCC [132]. GHG Protocol developed by the World Resources Institute and World Business Council for Sustainable Development is the most used standard for organizations and businesses, considering all three emission levels possible to be generated. In case of products methodologies, none of these has been sufficiently tested to determine its global applicability.

In Thesis, to assess the carbon balance at the individual farm level, emissions were calculated according to the 2006 IPCC guidelines for preparing national GHG inventories in combination with assumptions from scientific articles and sectoral experts. The basic equation (Eq.2.8.) is following [32]:

$$Emissions = AD \times EF \tag{2.8.}$$

where AD – activity data,

EF – emission factor.

To calculate emissions from fuel consumption, data from an agricultural farm in Latvia were collected. It is important to note that the results of the calculations may differ, if a more detailed calculation is made, considering factors such as soil consistency and the technologies used, off-road vehicles and other machinery efficiency and other indicators. It should also be emphasized that the more efficient techniques and methods are used, the lower emissions from maize production process are made.

First, the number of times specific off-road vehicles and other machinery - tillage techniques that use diesel fuel and the tons of diesel fuel consumed per 1 ha of the particular activity by off-road vehicles and other machinery were collected to an indicator of how many tons of diesel needed per hectare and how many tons of diesel fuel are consumed per year to process 1 ha of biogas maize fields. In turn, knowing the area of land that was used to grow the maize substrate for biogas in the given year, can provide an indicator of all year's fuel consumption for biogas maize cultivation per ha (Table 2.1).

Table 2.1

Diesel Fuel Consumption to Produce Maize for Biogas Production

	Times	**Fuel needed, t ha^{-1} at a time**	**Fuel needed, t ha^{-1}**	**Area, ha**	**Fuel consumed over the area, t yr^{-1}**
Ploughing	1	0.025	0.025	5382	134.3
Shuffle	1	0.008	0.008		44.8
Cultivation	1	0.007	0.007		40.3
Sowing	1	0.007	0.007		35.8
Plant protection + microelements	3	0.006	0.017		94.0
Shredding	1	0.029	0.029		156.7
Fertilizer application	3	0.004	0.012		67.2
Transportation field-farm	1	0.016	0.016		85.4
Compression	1	0.031	0.031		167.9
Picking from the pit, pouring, dumping	1	0.017	0.017		89.6
Incorporation of digestate into soil	1	0.015	0.015		80.6
In total	-	-	0.185		996.7

By finding out the lowest combustion heat of diesel fuel, it is possible to obtain consumed energy for field treatment [30]. But, knowing the energy consumed in the process in field cultivation as well as using EF from the 2006 IPCC guidelines, it is possible to obtain the result in terms of tons of emissions from the use of fuel [32]. By determining the annual emissions, indicator – emissions from the processing of 1 ha of maize used for biogas production – is calculated.

During the special cultivation of maize, fuel is not the only source of emissions, it is also caused by the incorporation of crop residues into the soil, as well as the use of nitrogen fertilizers and digestate.

N_2O emissions from managed soils were calculated using the Tier 1 methodology according to 2006 IPCC guidelines, including default emission factors [32]. For direct N_2O emissions calculation from agricultural soils management, the Equation 2.9 was used.

$$N_2O - N = [(F_{SN} + F_{CR}) \times EF], \tag{2.9}$$

where

$N_2O - N$ – direct N_2O-N emissions from N inputs to managed soils, kg N_2O–N yr^{-1};

F_{SN} – the amount of nitrogen in the fertilizer applied to the soil, kg N yr^{-1};

$F_{CR} - N$ – the amount of maize residues entering the soil on an annual basis (above and below ground), kg N yr^{-1};

$EF - N_2O$ – emission factor from N inputs, kg N_2O–N kg^{-1} N input (0.01).

Equation 2.10 was used to convert kg N_2O–N emissions to N_2O emissions:

$$N_2O = N_2O - N \times 44 \times 28. \quad (2.10)$$

One of the calculation parameters for estimating the direct N_2O emissions from the use of N in managed soils is the amount of pure nitrogen fertilizers per year. In order to calculate the data on the required inorganic fertilizers in the soil at farm level, the national standard [133] were used, which states that a maize yield of 31.8 t ha^{-1} requires 0,1 t ha^{-1} N fertilizers.

Yield N per year is calculated (Eq. 2.11) according to the Tier 1 methodology of the 2006 IPCC guidelines:

$$F_{CR} = Yield \times DRY \times Frac_{Renew} \times Area \times R_{AG} \times N_{AG} \times Area \times R_{BG} \times N_{BG} \quad (2.11)$$

where

$F_{CR} - N$ – the amount of maize residues entering the soil on an annual basis (above and below ground), kg N yr^{-1};

$Yield$ – harvested maize yield (kg fresh maize yield ha^{-1});

DRY – dry matter part of harvested maize, kg dry matter (kg fresh weight) $^{-1}$;

$Frac_{Renew}$ – total area of maize;

$Area$ – the total part of the area harvested for maize (ha yr^{-1});

R_{AG} – terrestrial, surface residue solids (AG_{DM}) and maize harvest (Crop), (kg dry matter kg^{-1} dry matter);

N_{AG} – N – surface plant residue content in maize, kg N (kg dry matter) $^{-1}$;

R_{BG} – the ratio of underground residues to maize yield (kg dry fraction kg^{-1} dry fraction), calculated by multiplying R_{BG-BIO} by the total aboveground biomass to cereal yield ratio (R_{BG} = [(AG_{DM} × 1000 + Crop) / Crop)];

N_{BG} – the N content of underground residues of maize, kg N (kg dry matter)$^{-1}$ (0.007) [134].

To calculate the annual production of crop residues F_{CR}, the following calculation (Eq. 2.12) is required:

$$R_{AG} = \frac{AG_{DM} \times 1000}{Crop}, \quad (2.12)$$

as well as additional equation (Eq. 2.13) to estimate terrestrial surface solids AG_{DM} (Mg ha^{-1}) [32]:

$$AG_{DM} = \left(\frac{Crop}{1000}\right) \times slope + intercept. \quad (2.13)$$

And the correction factor for estimating the dry matter yield is determined as in Equation 2.14:

$$Crop = Yield_{Fresh} \times DRY \tag{2.14}$$

where

Crop – harvested dry yield fraction T, kg dry matter ha^{-1};

Yield $_{Fresh}$ – part of fresh harvest T, kg fresh fraction ha^{-1};

DRY – dry matter fraction of harvested crop T, kg dry fraction, (kg dry fraction)$^{-1}$[32].

Although the use of digestate in field fertilization reduces emissions compared to synthetic fertilizers, digestion of soil with digestate also generates GHG emissions [135].

The results of analysis obtained from the farm producing biogas from maize indicate that the N content of the digestate fertilizer is on average 3.8 kg t^{-1}.

By knowing the N content of the digestate and the tons of digestate obtained, digestate fertilization emissions were calculated by equation from the 2006 IPCC guidelines.

When looking at emissions from the biogas production process, it should be considered that although biogas is produced from maize, which is a renewable resource and recovers the carbon emissions that the plant has absorbed during its growth process, emissions from the biogas production process are taken into account.

Based on the scientific article emission leakages account for 1 % of biogas losses in biogas production, which includes both the 52 % methane in it and the remaining 48 %, which is assumed to be carbon dioxide [136], [137].

Although GHG emissions result from field cultivation during maize cultivation, maize growth involves photosynthetic processes that sequester CO_2 from the atmosphere. In order to calculate the amount of CO_2 captured in a certain area of biogas maize, the amount of dry matter is multiplied by the CO_2 removal factor [138].

2.4. Multi-criteria decision analysis

Multi-criteria decision analysis (MCDA) is used to solve problems and evaluate the best possible solution. MCDA is the use of computational methods that include a number of criteria and a sequence of benefits for evaluating and selecting the best option among many alternatives based on the desired result. It consists of goal, decision maker's preferences, alternatives, criteria and outcomes [139]. At first define problem with alternatives, then find criteria which describes alternatives. After that find values for criteria and weights and use MCDA method to find best alternative for problem.

Because of the opportunity to easily compare different alternatives, TOPSIS method that solves the problems by ranking alternatives from distance from positive ideal solution and negative ideal solution was used. MCDA allows for the assessment and prioritization of different technologies from technical, ecological, economic, and social perspectives. The MCDA method focuses on decisions influencing local problems. An analysis of the structure of the problem under the study is crucial for understanding the causes of the system's behaviour and in determining an action plan for managing the situation.

Within the MCDA, the choice of the criteria categories is crucial, because a quantitative evaluation must be carried out in relation to reference indicators provided.

The TOPSIS calculation framework is based on seven main steps [140] such as demonstrate a performance matrix, normalize the decision matrix, calculate the weighted normalized decision matrix, determine the positive ideal and negative ideal solutions, calculate the separation measures, calculate the relative closeness to the ideal solution, rank the preference order.

The basic element of the TOPSIS analysis is a data matrix, where evaluation criteria are represented by $x_1, x_2, .., x_j, \ldots, x_n$ (Eq. 2.15):

$$\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccccc} x_1 & x_2 & \cdots & x_j & \cdots & x_n \end{array} \\ \begin{bmatrix} x_{11}^k & x_{12}^k & \cdots & x_{1j}^k & \cdots & x_{1n}^k \\ x_{21}^k & x_{22}^k & \cdots & x_{2j}^k & \cdots & x_{2n}^k \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1}^k & x_{i2}^k & \cdots & x_{ij}^k & \cdots & x_{im}^k \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{n1}^k & x_{n2}^k & \cdots & x_{nj}^k & \cdots & x_{nm}^k \end{bmatrix} \end{array} \tag{2.15}$$

After compiling the matrix, the data are normalized using the following methodology (Eq. 2.16):

$$n_{ij} = \frac{x_i j}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}\ , \tag{2.16}$$

where

x_{ij} – criteria value.

Next step is weighted normalized decision matrix values (vij) calculation from equation (Eq. 2.17).

$$v_{ij} = w_j n_{ij}, \tag{2.17}$$

where

w_j – criteria weight,

n_{ij} – normalized matrix value.

Then defining the ideal and non-ideal solution for each criterion from equation (Eq. 2.18) and equation (Eq. 2.19.) must be evaluated:

The positive ideal solution A^+ has the form:

$$(A^+ = \max v_{ij} \mid j \in I), (A^+ = \min v_{ij} \mid j \in J) \tag{2.18}$$

The negative ideal solution A^- has the form:

$$(A^- = \min v_{ij} \mid j \in I), (A^- = \max v_{ij} \mid j \in J) \tag{2.19}$$

where

I – is associated with benefit criteria and J with the cost criteria [152].

The next, the separation measures from the positive and negative ideal solutions have to be calculated according to equation (Eq. 2.20) and equation (Eq. 2.21).

$$d_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2}\,, i = 1,2, \dots m \quad (2.20)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2}\,, i = 1,2, \dots m \quad (2.21)$$

After finding the d_i^+ and d_i^- – values, the relative closeness of the i-th alternative Aj with respect to A^* (closeness of each alternative for ideal solution) is defined according to equation (Eq. 2.22.):

$$R_i = \frac{d_i^-}{d_i^- + d_i^+} \quad (2.22)$$

where i = 1, 2, …., m [141].

As final step - Output: best alternative is with highest closeness.

Multi-criteria analysis was carried out to determine the potential of Latvia's biogas sector, to predict the best feedstock depending on the resources available in the country and which of the substrates has the highest potential and sustainability for biogas production.

The Thesis compares 8 substrates with 3 different parameters – economic feasibility, environmental friendliness and technological aspect – efficiency. The following raw materials were analysed: cattle manure, pig manure, poultry manure, sewage sludge, organic waste, wood, straw, and maize silage.

The year 2017 was used for data collection, and multi-criteria analysis does not take into account the size of the farms, which is related to the actual number of livestock, manure collection technology and the transportation distance from the raw material extraction site to the biogas plant.

For the purpose of multi-criteria analysis, the efficiency of different feedstocks in terms of yield, i.e., how many cubic meters of biogas can be obtained from a ton of a given feedstock was analyzed. The efficiency of raw materials was determined as an average value [142], [143].

To determine the importance of using a particular substrate in the production of biogas, data was collected on how many emissions could be eliminated altogether, thus approximating the proportion of their availability and importance, and environmental impact depending on the amount this material is produced in one year and taking into account its emission factor. To calculate the amount of GHG emissions that could potentially be avoided both N_2O and CH_4 emissions were expressed to CO_2 equivalent [27].

In order to determine the most important criteria, a survey and an expert judgment was carried out among different experts in the field of biogas production. As a result, the most important criteria were impact on climate and efficiency with 35 % for each, the technological aspect was less important only –5 %.

To evaluate the potential of manure for biogas production, a summary was made, which is shown (Table 2.2), to summarize the amount of specific livestock manure and emissions in Latvia in one year.

Table 2.2

Characteristics of livestock numbers and emissions from manure management in 2017 [144]

	Mature dairy cattle	**Other mature cattle**	**Growing cattle**	**Pig**	**Poultry**
Population size (thousands)	150.4	77.5	177.9	320.6	4943.8
CH_4 emissions (kt)	2.60	0.15	0.20	0.79	0.07
CH_4 emissions (kt CO_2 eq.)	65.00	3.75	5.00	19.75	1.75
N_2O emissions (kt)	0.11	0.01	0.02	0.02	0.01
N_2O emissions (kt CO_2 eq.)	32.78	2.98	5.96	5.96	2.98
GHG emissions in total (kt CO_2 eq.)	97.78	6.73	10.96	25.71	4.73

Since the information about livestock population and emissions for 2017 is available, it is used for the analysis. Table 2.2. shows that although poultry has the highest numbers, CH_4 emissions from cattle are the highest and to use them for biogas production would be more significant, if only by looking at annual emissions, because altogether cattle emissions reach 115.47 kt CO_2eq./year. Pig manure is also a very important resource, although the number of pigs is 21 % lower, emissions emitted are still significant.

Domestic and industrial wastewater emissions are calculated and shown in Table 2.3.

Table 2.3

Domestic and industrial wastewater emissions

Wastewater dry content and emissions in 2017 [29]	Total organic product (kt DC/year)	CH_4 emissions (kt)	CH_4 emissions as CO_2 eq. (kt)	N_2O emissions (kt)	N_2O emissions as CO_2 eq. (kt)	In total (kt CO_2 eq.)
Domestic wastewater	42.71	3.16	79.00	0.11	32.78	111.78
Industrial wastewater	13.51	0.07	1.75	0.00	0.00	1.75

Methane emissions from solid waste are shown in Table 2.4. In total both, managed and unmanaged waste disposal sites emit 403.50 kt CO_2 equivalent per year, because of the organic waste in disposal sites. This problem could be partly overcome by changing the shopping and eating habits of population, thus reducing the amount of food thrown away. However, such a shift in behavior takes a long time, and until it is successful, this "waste" can be used effectively in biogas production, because it is creating the largest emissions of all analyzed raw materials in this research.

Table 2.4

Annual solid waste emissions in 2017 at the waste disposal sites [144]

	Annual waste (kt)	CH_4 emissions (kt)	CH_4 emissions (kt CO_2 eq.)
Managed waste disposal sites	230.62	10.55	263.75
Unmanaged waste disposal sites	-	5.59	139.75

2.5. Combination of Delphi approach and MCDA

One of the aims of this study is to develop a methodological approach for estimating GHG emission reductions to assess progress towards result-based agriculture and to contribute to climate goals. Therefore, the combination of the Delphi method and multi-criteria analysis is used as a methodological concept to achieve the goals for Tasks 5 and 6. (Fig.2.4).

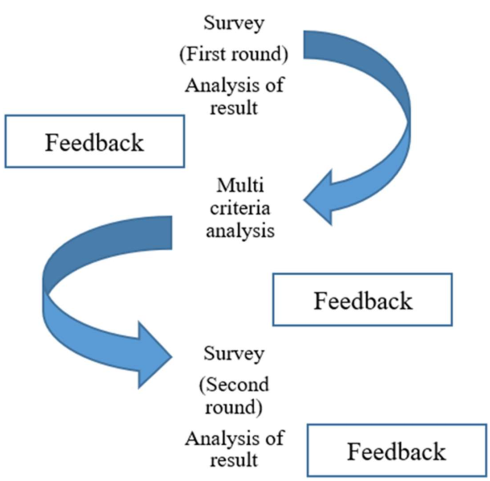

Fig.2.4. Scheme of the used Delphi technique and TOPSIS for analysis

The Delphi approach was used to get an expert opinion regarding existing and planned policies and measures for GHG emission reductions in the agriculture sector. The aim of the method is to collect the opinions and judgments of experts about issues in terms of possibilities in the future, likelihood and usefulness of implementation [145]. The approach of the method – the opinions of the experts are summarized in a process of communication by a planned group [146]. The method of Delphi is formulated on the idea that future predictions from a planned group of individuals are more precise if compared to unplanned groups [147]. The main characteristics of the Delphi method is that experts can remain anonymous, management of the survey is organized in several rounds, and feedback can be sought from the experts. Experts were selected according to their competences. Nineteen GHG reduction measures for WEM and WAM scenarios were included in the survey. These measures are taken from Latvia's latest submitted fourth biennial report [148] to the UNFCCC and from Latvia's NECP [2]. Each of the experts was asked to assess these nineteen mitigation measures from an economic, engineering-technical, environmental/climate and social aspect.

The initial input of the experts is in the form of answers to the questionnaire and their comments on these answers. The questionnaire was sent to 25 experts with knowledge on the issue. The experts were asked to prepare their own opinion/prediction. All participants remained anonymous. 18 experts answered the questionnaires in two rounds. The experts also provided answers and additional descriptions and judgments.

Between these two rounds of the survey, a MCDA was performed (Fig.2.5) that allows for the prioritization and assessment of different measures from the economic, technical, environment/climate and social perspective. It is stated by Pubule, et al., that MCDA generally includes a weighted set of criteria [149]. To assess and find the most optimal scenario, TOPSIS was used, which was made by Hwang and Yoon [150]. The goal of this approach is to help in making a decision by grouping alternatives according to how they fit in with the best solution [151]. A more detailed description on the MCDA TOPSIS method is provided in chapter 2.4.

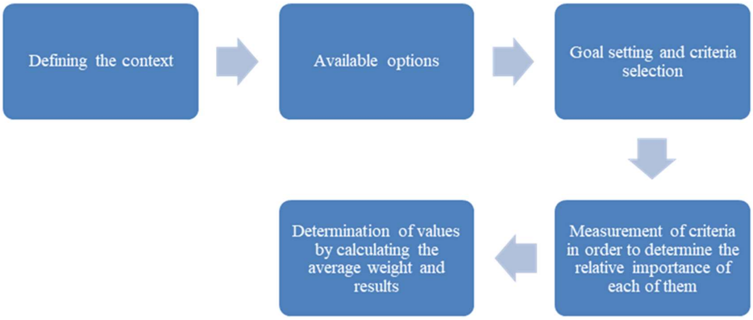

Fig.2.5. Steps for Multi-Criteria Decision Analysis

Additionally, experts were asked to consider the replies of the first round and the answers of other experts to get an overview/opinion regarding future projections for the most appropriate measures for GHG reduction and for a move to smart agriculture, where the efficient use of resources is one of the main goals.

A set of scenarios WEM and WAM policies and measures implemented, adopted and planned in Latvia's BR4 and NECP 2021–2030 focuses on developing programs and implementing measures on farms in different clusters, to reduce GHG emissions from the agriculture sector. The following key policies and measures were reported in Latvia's BR4 [148]:

- increased land area of organic farming,
- legumes growing,
- support for advancing precision farming technologies and livestock feeding practices,
- promoting the reduced use of nitrogen fertilizers, including biogas production,
- maintenance of amelioration systems.

As the trend of GHG emissions from the agriculture sector shows an increase of emissions, the NECP address the following actions to solve this problem:

- measures to promote the precise and efficient use of fertilizers,
- direct injection of slurry in soil,
- measures to improve soil fertility – maintenance of drainage systems,
- nitrogen sequestering crops as a part of crop rotation, under sowing grass,
- green fallow,
- measures that improve animal nutrition – improvement of feed quality,
- feed ration planning,
- measures to improve manure management systems – promotion of biogas production; organic dairy farming [152].

Unfortunately, it is observed that a budget is not provided for all planned measures, therefore the implementation of these measures may be jeopardized. The research of the Latvia University of Life Sciences and Technology related to GHG reduction measures has been used to determine appropriate additional measures and policies for the national agriculture sector within the framework of the NECP [2], [154].

Popluga D., Naglis–Liepa K. indicate that beneficial management practices are one of the globally most recognized methods to evaluate GHG emission potential and applied this approach to determine the following measures as the most appropriate – introduction of leguminous plants on arable land, nitrogen balance, lengthened grazing season, strategies of feeding, production of biogas [155-156]. To evaluate the more eligible GHG emission decreasing measures for Latvia, a marginal abatement cost curve (MACC) was used [157]. Below are reflected short descriptions of some of the GHG reduction measures and policies for WEM and WAM scenarios for the agriculture sector according to Latvia's BR4 and NECP [148], [2]:

– *Use of precision agriculture technologies in farms for crop growth to reduce use of nitrogen* – related with the use of nitrogen fertilizer reduction and thus reduction of nitrogen leaching and run-off. This measure reduces nitrous oxide emissions from agricultural soils,

- *Promotion of precision cattle feeding approach, including feeding plan development and support the use of good quality feed for increasing digestibility* – the aim of this implemented measure is to contribute to the use of good quality food for livestock thus decreasing methane emissions and increasing digestibility,
- *Introduction of leguminous plants on arable land* – related to the use of pulses as fodder and manure in the rotation of crops and thereby contributing to the use of nitrogen fertilizer reduction. This measure could reduce emissions of nitrous oxide from the use of inorganic N fertilizers and organic N fertilizers. Financial support is provided for the implementation of this measure according to national legislation,
- *Management of nitrate vulnerable territories* – related to the restriction of nitrogen usage and thus nitrogen leaching reduction as well as protection of water pollution from nitrates,
- *Water and soil protection requirements from pollution-related nitrates* – measure to restrict nitrogen usage and reduce nitrogen leaching. This measure reduces indirect N_2O emissions from managed agricultural soils,
- *Crop fertilization plans in vulnerable zones* – measure for farmers in highly vulnerable areas who have an area of 20 and more hectares and grows potatoes, vegetables and are required to document the field history for at least three years if fertilizers are used.
- *Requirements for manure storage and spreading* – related to requirements of manure storage outside the animal shed and is for farms in vulnerable territories,
- *Maintenance and modernization of amelioration systems on agricultural land* – measure reduces indirect N_2O emissions from N leaching and run-off from agricultural land and is used for implementation in croplands on mineral soils, where, due to unfriendly circumstances, are not easy to get high yields, especially in the spring time, which are induced by drainage systems wearing. Financial support for renovation of a drainage system is made according to established national legislation. Modernization of amelioration systems on agricultural land is planned to increase arable land area with improved and maintained amelioration systems, thereby reducing nitrogen leaching and run-off from agriculture land,
- *Promotion of biogas production* – measure for usage of bioresources (mainly or only manure) to produce biogas which is used to generate electrical and/or thermal energy. By implementing this measure, the manure is efficiently used, the odor is reduced, and a high-quality fertilizer called digestate is obtained,
- *Organic farming land area increase* – related to methods of farming with inorganic nitrogen fertilizers use reduction and leaching, increased biodiversity and environmentally favorable impact on nature,
- *Extensified crop rotation* – related with use of green manure in rotation of crops and promoting organic dairy farming. The main aim of the measure is to promote transition of small and medium-sized conventional dairy farms to the organic

farming system, thus facilitating low emission dairy farming,

- *Support for fertilization planning* – the main aim of the measure is to expand arable land and increase the number of medium-sized crop and livestock farms where fertilization planning and practical implementation that is based on knowledge about agrochemical properties of soil has not been done previously,
- *Promote inclusion of leguminous plants in crop rotation for nitrogen fixation* – the main aim of the measure is to expand arable land and increase number of farms where leguminous plants are included in crop rotation thus contributing to atmospheric nitrogen fixation and reduction of application of inorganic nitrogen fertilizers,
- *Promote and support for precision application of inorganic nitrogen fertilizers* – related to expanding arable land and increasing number of farms where precision technologies for application of inorganic nitrogen fertilizers are used in the planning of fertilizer schemes and spreading,
- *Promote and support for direct incorporation of organic fertilizers into the soil* (using specific technology) – related to expanding arable land where organic fertilizers are directly incorporated into the soil thus promoting more efficient use of organic fertilizers,
- *Promote feed ration planning* – related to increased number of cows the feed rations of which are balanced for reduced crude protein level without loss in milk production,
- *Promote improvement of feed quality* – related to increasing the number of cows who are fed with feed (in this measure special attention is paid to hay, hay silage, grass silage) with high digestible energy (i.e. digestible energy is more than 68 %),
- *Promote biogas and biomethane production and biomethane use* – related to ensure the installation of biogas production and biogas purification (biomethane production) facilities on farms that have not yet had biogas production and purification facilities,
- *Support the development of innovative technologies and solutions to promote resource efficiency, GHG reduction/CO_2 sequestration in agriculture* – measure whereby support will be provided for the development of the new technologies and innovative solutions for GHG emission reduction and increase of CO_2 removal. Unfortunately, the financial source is not indicated.

2.6. Combination of comparative and multi-criteria decision analysis

The Thesis used a combination of comparative analysis and MCDA TOPSIS to evaluate the GHG emission trends, including possible mitigation measures in the Baltic States and possible alternatives of cereals, to assess the highest added value of using the product from the perspective of climate neutrality and sustainable agriculture.

In the first part of the study, the available literature has been examined as well as the comparative analysis method to assess the 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 [148], [158], [159] submitted by the Baltic countries to the UNFCCC.

In the second part of the study, the literature review was first carried out [160], [162]. Based on the review, a questionnaire was developed to evaluate the use of cereals and straws for 4 groups of products (food, pharmaceutical, straw products, and transport).

Then, a survey was developed and sent to respondents electronically with a request to provide an assessment of use of cereals and straw. 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.

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 for the survey were selected based on their experience and knowledge of the sector. The questionnaire was sent to 20 sectoral experts, and responses were received from all the respondents. In order to achieve a 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, bars, gluten, starch, alcohol, kvass, beer, coffee, oil, ethyl alcohol, antioxidants, vitamins, minerals, lignans, proteins, bioethanol, biogas, biohydrogen. The selected straw products included litter in barns, granules, fibers, disposable tableware, drinking straws, reusable tableware, bioplastic.

Once the assessments have been obtained, a MCDA was performed using the TOPSIS method for all selected factors that is one of the most used methods in working with MCDA and allows to easy compare different alternatives. Analysis of the results based on MCDA TOPSIS were carried out in two steps to determine the best alternative for each of the product group separately, then, after the alternatives with the highest single variation ratio in each product group had been obtained, additional MCDA analysis was performed to determine the leading alternative.

The evaluation process is presented in Fig. 2.6.

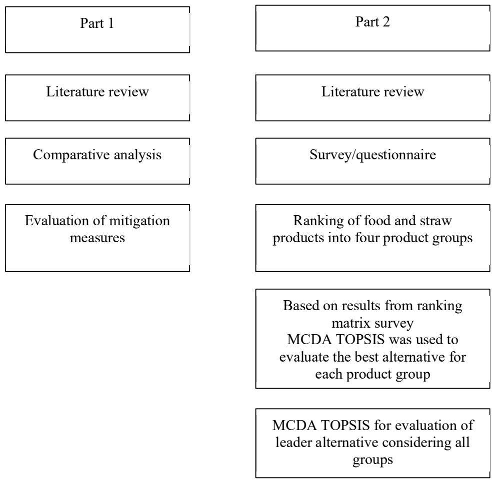

Fig. 2.6. Framework of methodology

3. RESULTS

3.1. Empirical model for evaluating eco-efficiency

To begin with, an eco-efficiency assessment was performed. Mainly data from the CSB and Latvian Environment, Geology and Meteorology Centre (LEGMC) were analysed, as they are the main data sources for official reports of Latvia submitted to different international institutions. The data is presented mostly at national and regional level. For this study mainly the activity data regarding economic activities of agriculture in 2000-2014 at national level were used, but in some cases in 1990. Data on GHG emissions were taken from national annual GHG inventories reported within the framework of the UNFCCC [163]. Other activity data were used from the databases of LEGMC. It was concluded that full data set at farm level regarding agriculture emissions is not available. In some cases, data are not disaggregated enough. Regression analysis was used for the relationship assessment between the GHG emissions and product production and other parameters.

The results of calculation of the chosen indicators for eco-efficiency evaluation in agriculture sector are summarised in Figs. 3.1–3.4.

First, energy intensity was analysed (Fig.3.1.) where noticeable data fluctuations can be observed, which can be explained with lack of data correlation between the fuel consumption and GDP. The linear graph shows amount of fuel used in sector corresponding with sector GDP. For example, in 2001, compared to 2000 the amount of fuel used in the sector increased by 9.3

%, which was similar to GDP that increased by 8.9 % in the same time period, but in 2001–2002, the amount of fuel used in the sector decreased by 7.1 % and GDP sharply decreased by 13.5 %. Similar situation can be observed through whole time series. Most significant deflection from the trend-line is in the year 2008 (–9.3 %) and 2009 (–13.3 %) due to inconsistent changes in fuel consumption and GDP. While in 2007–2008 fuel consumption dropped by 16.3 %, for GDP it was only –6.6 %, similar situation with 2007–2009 when fuel consumption decreased by 10.5 %, while GDP increased by 5.3 %. In these years, Latvia went through economic crisis that left noticeable impact in all sectors not only agriculture. Also, one of the most used fuels in agriculture sector is diesel oil (~60–80 % from the total consumption) that has a large statistical difference due to illegal import from neighbouring countries. At the same time, when economic situation was stabilized in the country, energy intensity stabilized as well. The trend of energy intensity is negative linear, which means that energy saving technologies are used.

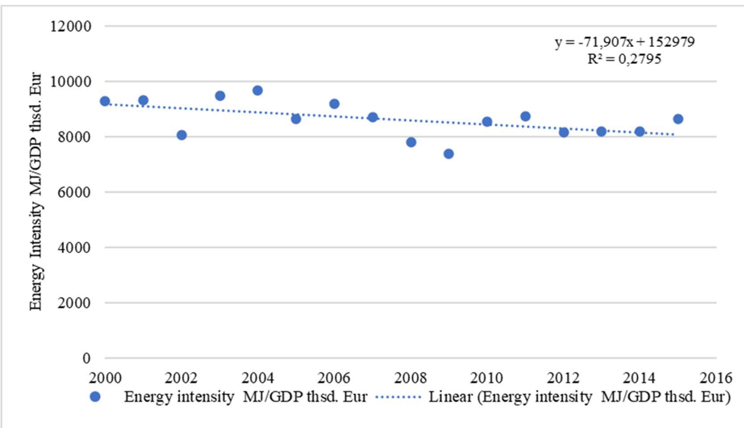

Fig.3.1. Energy intensity MJ/GDP

Secondly, CH_4 and N_2O emission intensity in the agriculture sector were analysed (Figs. 3.2–3.3). A close correlation between CH_4 emissions and livestock production – output of meat and milk have been observed, while in the crop production a weak correlation between the production of grain, potatoes and vegetables, and the amount of nitrogen oxide emissions have been noticeable. The reason for that could be the fact that total N_2O emissions include the emissions from management of organic soils and pasture that are not directly related to the crop production. Essential elements in the production of crops are consumption of nitrogen fertilizers as well as use of organic fertilizers, which more accurately show relationships between the crop output and emissions of N_2O.

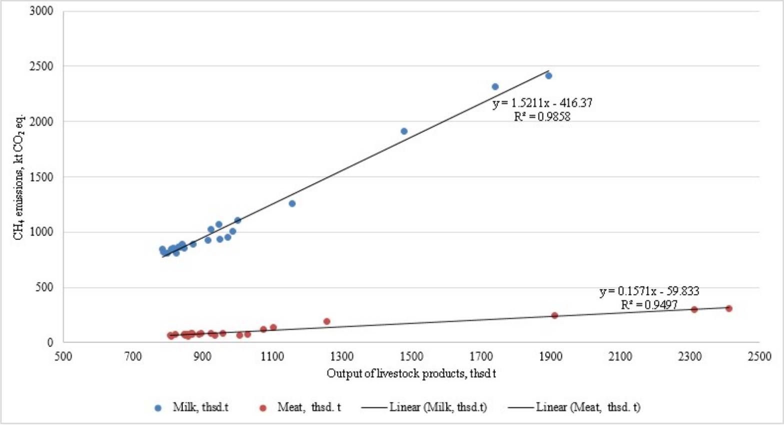

Fig. 3.2. Link between CH_4 emissions (kt CO_2 eq.) and meat and milk production

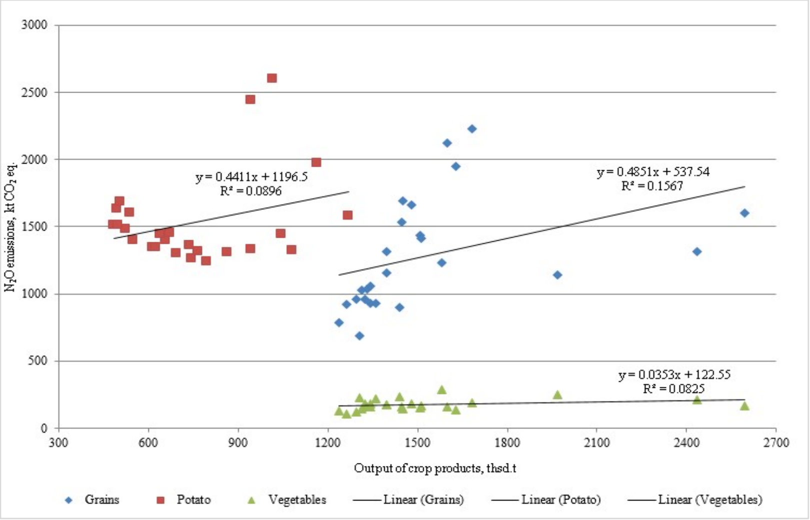

Fig. 3.3. Link between the crop production and N_2O emissions (kt CO_2 eq.)

Overall analysis of the eco-efficiency in the agriculture sector is presented in Fig.3.4, where total GHG emissions, GDP, used energy consumption, use of agricultural area, crop production and other parameters in the sector are included. As it can be seen in Fig.3.4, GHG emissions in agriculture sector (~28 %) and GDP (~48 %) have growing tendency from 2000 till 2014, but it is important to point out, that GHG emissions mainly have been increasing due to the application of N fertilizers to soils and management of organic soils. And the use of N fertilizers has been weakly correlating with crop yields – it means that the consumption of N fertilizers is growing, but crop yields do not grow accordingly in the period used for analysis, especially in 2009–2011. This graph explains the weak relationship between the N_2O emissions and production of crop products mentioned above. It can be seen that there is a significant increase in use of nitrogen fertilizers, but the crop output growth is ambiguous, perhaps it could be linked to the impact of agro-meteorological conditions.

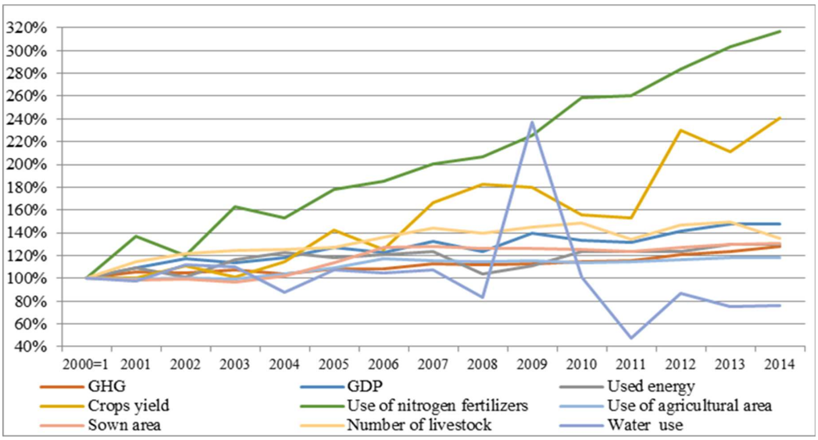

Fig.3.4. Changes (%) of main indicators in agriculture in 2000–2014 (2000=1)

Water use data [164] shows that it has a strong tendency to slowly decrease, and it can be explained by more efficient use of water. Some outliers of data (for years 2009 and 2011) seem to be caused by insufficient quality of data.

3.2. GHG emission reduction model

To propose a tool with a set of indicators for the assessment of GHG emissions mitigation measurements for agriculture sector the theory-based analysis was performed; first, available agri-environmental indicators were analysed, then mitigation measures and their effect. The goal of the proposed set of indicators is mostly meant for decision makers to estimate the agriculture development options and to evaluate the sustainability of agriculture proposals and production of agriculture products with high added value. It is also important to evaluate a comprehensive set of indicators in order to assess the actual impact on the results of the first set of indicators selected.

Indicators used for evaluation of GHG emissions from agriculture

The EC has developed 35 agri-environmental indicators for assessing impacts of agriculture [165], [166]. From these indicators 11 indicators (Table 3.1) are set as relevant to the assessment of agriculture in relation to climate change and air quality: mineral fertilizer consumption, energy use, cropping/livestock patterns, farm management practices – manure management, atmospheric emissions of ammonia from agriculture, emissions of CH_4 and N_2O from agriculture, share of agriculture in GHG emissions, area under agri-environment support, regional levels of good farming practice, regional levels of environment targets and production of renewable energy.

Table 3.1

Agri-environmental indicators

Indicator	Parameter, unit
Mineral fertilizer consumption	Application rates (kg/ha of N and P)
Energy use	Total direct energy use at farm level kgOE per ha per year
Cropping/livestock patterns	Share (%) of main agricultural land types (on total UAA. Total livestock density (LSU/ha of utilised agricultural area (UAA))
Farm management practices – manure management	Share of holdings with livestock which have manure storage facilities in total holdings with livestock Share of holdings with livestock which have manure storage facilities in total holdings with livestock
Atmospheric emissions of ammonia	Ammonia emissions (kilotons per year)
Production of renewable energy	Share of primary energy production of renewable energy from agriculture and forestry to total energy production
GHG emissions	CO_2 equivalents (kilotons per year)
Emissions of methane (CH_4) and nitrous oxide (N_2O)	kilotons per year
Area under agri-environment support	ha
Regional levels of good farming practice	
Regional levels of environment targets	

Mitigation of GHGs emissions related to agriculture consist of following categories, depending on the underlying mechanism:

- Decrease in emissions;
- Avoiding (or displacing) emissions [167], [169].

GHG emissions from agriculture are associated with certain concerns, therefore the evaluation of GHG mitigation measurements can be challenging [168]. This makes consensus difficult to analyse performance of EU Member States in intensity of emissions.

Table 3.2

Mitigation measures [168]

Field	Mitigation effect
Cops and farming system management	Reduction of GHG emissions Reduces direct N_2O and indirect N_2O emissions
Fertilizer, manure, and biomass management	Reduction of GHG emissions
Soil management	Increases soil organic carbon, reduces GHG emissions
Animal husbandry	Reduces methane emissions per kg meat Reduces emissions per kg output
Energy use	Reduces fossil emissions

GHG emissions mitigation measurements assessment indicators

Indicators for the assessment of soil carbon level, closed nutrient cycles, consumption and waste patterns, N_2O dynamics, assessment of multi-functional farming systems, energy use, and production of renewable energy were developed for the evaluation of the GHG emissions mitigation measurements. In the Thesis, selected indicators were settled by reviewing literature and based on the opinion of experts in this field. Six major indicators groups, consisting of a combination of 11 agri-environmental indicators were used to evaluate the climate friendly agriculture (including the assessment of GHG emission mitigation) and bioenergy development options (Table 3.3).

Table 3.3

GHG Emissions Mitigation Measurement Indicator

GHG emissions mitigation measurement indicator	Analysed changes in values	Agri-environmental indicator
Changes in soil carbon	Increase in soil carbon	• Mineral fertilizes consumption
Closed nutrient cycles	Realise closed nutrient cycles in agriculture	• Farm management practices – manure management • Atmospheric emissions of ammonia from agriculture
Consumption and waste patterns	Change consumption and waste patterns	• Cropping/livestock patterns
Nitrous oxide dynamics	Reduction of N_2O emissions	• Emissions of CH_4 and N_2O • GHG emissions

GHG emissions mitigation measurement indicator	Analysed changes in values	Agri-environmental indicator
Multi-functional farming systems	Development of multi-functional farming systems	• Area under agri-environment support • Regional levels of good farming practices • Regional levels of environmental targets
Energy use and production	• Increase production of renewable energy • Decrease energy used at farm level	• Production of renewable energy • Energy use

Criteria weights were determined by sectoral experts. Normalized and weighted values of indicators for the evaluation of GHG emissions mitigation for agriculture sector are shown in Fig. 3.5.

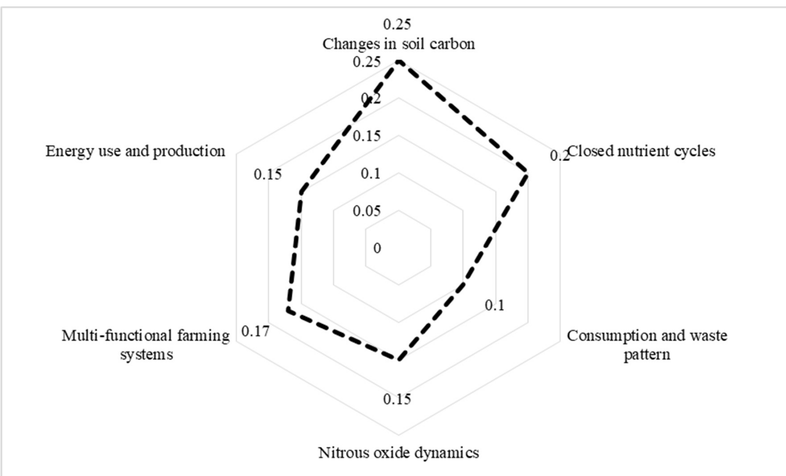

Fig.3.5. Decision-making matrix

3.3. Carbon balance at individual farm level

For the analysis of cultivation of maize and GHG emissions related with it, the 2006 IPCC guidelines and data about the amount of total cultivated maize from 2017 were used. According to results, it is concluded that in 2017 GHG emissions are generated from the cultivation of maize, which was used as a substrate for biogas production, in total 3.53 kt CO_2 eq.yr^{-1} to treat it with heavy agricultural machinery. Knowing that 5382 ha of biogas maize were managed in

2017, a result is obtained showing that 0.66 tCO_2 eq. ha^{-1} per year of GHG emissions are generated in the management of biogas maize fields with agricultural machinery.

Table 3.4 shows fuel emission indicators per 1 ha of cultivated maize area used in calculations.

Table 3.4

Fuel emission indicators per 1 ha of cultivated maize area [32]

	CO_2 emissions, t ha^{-1}	CH_4 emissions, kg ha^{-1}	N_2O emissions, kg ha^{-1}
Ploughing	0.079	0.004	0.030
Shuffle	0.026	0.001	0.010
Cultivation	0.024	0.001	0.009
Sowing	0.021	0.001	0.008
Plant protection + microelements	0.055	0.003	0.021
Shredding	0.092	0.005	0.035
Fertilizer application	0.040	0.002	0.015
Transportation field-farm	0.050	0.003	0.019
Compression	0.099	0.006	0.038
Picking from the pit, pouring, dumping	0.053	0.003	0.020
Incorporation of digestate into soil	0.048	0,003	0.018
In total	0.588	0.033	0.225

In order to evaluate the total GHG emissions from fuel use, emissions were converted into a CO_2 equivalents (CO_2 eq.). Table 3.5 shows the CO_2 eq. emission indicators per 1 ha of biogas produced from specially cultivated maize.

Table 3.5

Fuel Emission Indicators per 1 ha of Biogas Produced from Cultivated Maize [32]

	CO_2 emissions, kg CO_2 eq. ha^{-1}	CH_4 emissions, kg CO_2 eq. ha^{-1}	N_2O emissions, kg CO_2 eq. ha^{-1}	Total GHG emissions, t CO_2eq. ha^{-1}
Ploughing	79.28	0.11	9.04	0.09
Shuffle	26.43	0.04	3.01	0.03
Cultivation	23.78	0.03	2.71	0.03
Sowing	21.14	0.03	2.41	0.02
Plant protection + microelements	55.49	0.08	6.33	0.06
Shredding	92.49	0.13	10.55	0.10
Fertilizer application	39.64	0.06	4.52	0.04
Transportation field-farm	50.42	0.07	5.75	0.06
Compression	99.09	0.14	11.30	0.11
Picking from the pit, pouring, dumping	52.85	0.07	6.03	0.06
Incorporation of digestate into soil	47.57	0.07	5.42	0.05
In total	588.16	0.82	67.06	0.66

The obtained data show that the highest emissions per ha occur per year due to harvesting and shredding to prepare maize for placing in the bioreactor, as well as due to compaction. The lowest emissions occur during sowing. Total indicative emissions from biogas production from specially grown maize per ha are shown in Table 3.6.

Table 3.6

Total Indicative Emissions from Biogas Production from Grown Maize in 2017 per ha [32]

Indicative emissions	t CO_2 eq. ha^{-1}
Fuel emissions	0.656
Crop residue emissions	0.443
N fertilizer emissions	0.468
In total	1.567

As a result, it can be seen that the highest emissions per ha are caused by the use of fuel to perform all the necessary treatment operations with heavy machinery, which is almost 0.66 tCO_2 eq. ha^{-1}. Emissions from tillage with nitrogen fertilizers and crop residue incorporation in soil after harvest are relatively similar, amounting to 0.468 tCO_2 eq. ha^{-1} and 0.443 tCO_2 eq. ha^{-1}. In total, indicative emissions from biogas production from specially grown maize creates 1.567 tCO_2 eq. ha^{-1}.

The biogas production process produces a valuable by-product – digestate. It contains significant amounts of nutrients that are suitable for enriching the soil [170]. The dry weight of digestate from biogas production using only maize is approximately 58.22 % [171]. Digestion of fields with digestate can indirectly reduce GHG emissions, for example, digestate from 1 ha of maize green matter with a yield of 30 t ha^{-1} fully provides the required amount of potassium fertilizer and saves 31 % phosphorus and 44–45 % nitrogen fertilizer [172], [173].

Accordingly, using a maize yield of 31.8 t ha^{-1}, it is possible to provide fertilizer for 1.06 ha of maize. As a total of 25 700 ha of maize was grown in Latvia in 2017, the use of digestate is topical, as well as interviews with Latvian farmers conducted within the framework of this Thesis revealed that unfortunately digestate for field fertilization is a shortage product, which is why additional synthetic fertilizers are used [174], [175].

Using digestate fertilizer in tillage, 1.19 $ktCO_2$ eq. emissions were saved in 2017, while indicative emissions show a reduction of 0.22 tCO_2 eq. ha^{-1}.

Although the use of digestate in field fertilization reduces emissions compared to synthetic fertilizers, digestion of soil with digestate also generates GHG emissions. The results of analysis obtained from a farm producing biogas from maize indicate that the N content of the digestate fertilizer is on average 3.8 kg t^{-1}. Assuming that the maize harvest in 2017 is 171,147.6 tons and that the amount of digestate from the amount of mass fed to the bioreactor usually ranges from 90 to 95 %, in 2017 158 311.53 tons of maize digestate were obtained, while knowing the N content of digestate per 1 ton, it is obtained that the total N per 5382 ha of the whole maize area was 0.60 kt [176]. Based on the Tier 1 methodology of the 2006 IPCC guidelines, it is estimated that digestate fertilization caused 2.82 ktCO_2 eq. emissions in 2017 indicating on indicative emissions – 0.0005 tCO_2 eq. ha^{-1}. The CH_4 content of biogas produced exclusively from maize silage is known to be 52 %, and the biogas yield per ton of maize is 202 cubic meters, which allows to calculate both the total amount of biogas produced from maize harvested in Latvia, which is 34 571 815.2 m^3 from 171 147.6 t maize [163]. At a 1 % biogas leak in its production process in 2017, 2.63 kt CO_2 eq. GHG emissions were released into the atmosphere.

Despite the consumption of diesel fuel and emissions from the maize production process, maize absorbs much more carbon than is produced during photosynthesis, thus, if 1% of biogas leakage is assumed in its production process, as well as knowing by previous calculations that 34 571 815.2 m^3 of biogas can be obtained from 5 382 ha specially grown maize, its production from specially grown maize can save 1.86 kg CO_2 eq. emissions per 1 m^3 of produced biogas (in normal conditions, pressure 760 mm Hg).

3.4. Bioresources ranking at technology level

To evaluate the best raw material for biogas production, the MCDA TOPSIS model was developed. To determine which feedstock is most economically advantageous for biogas production, information on feedstock prices was collected. The largest advertisement portal in Latvia was used to find out the price of manure, as well as straw and corn, which showed that, on average, cattle manure is sold for 3 €/t, poultry manure for 2 €/t, but pig manure is charged a very symbolic price of about 1 €/t [177]. Straw bales were found to weigh an average of 0.45 t, but 1 bale is sold for an average of 7 €/piece, while 1 t of corn silage costs 50 € [177]. By making the calculations, 1 t of straw costs 15.56 €/t. A symbolic price of 1 /t was adopted for wastewater sludge. The price of organic waste was determined by obtaining information on the website of the largest landfill site in Latvia, where it is offered to deliver the organic waste to landfill for 60.81 €/t +VAT. It means that the cost of transferring the waste in total with VAT costs is 73.58 €/t [178]. As the transfer of this waste costs a certain amount of money, its use at the on-farm biogas plant means a reduction in costs and for that reason the cost of organic waste is shown with a minus sign in tab. 3.7. According to surveys of the biggest woodchip suppliers, its price is currently 12 €/m^3. Given that 1 t of woodchips is equivalent to 3.5 m^3 of woodchips, the price per t is assumed to be 42 €.

Summarizing the information obtained on the biogas efficiency of the feedstock as well as the price per t of the feedstock, it is possible to obtain an economic justification for each substrate (Table 3.7). To obtain the cost of producing 1 m^3 of biogas from a given substrate, the substrate price was divided by the substrate efficiency.

Table 3.7

Calculation of Economic Justification for Each Substrate

	Effective (yield of biogas, m^3/t)	Price of the feedstock (€/t)	Economically justified (€/m^3 biogas)
Cattle manure	35	3.00	0.09
Pig manure	44	1.00	0.02
Poultry manure	80	2.00	0.03
Sewage sludge	218	1.00	0.01
Organic waste	100	-73.58	-0.74
Wood	35.5	42.00	1.18
Straw	190	15.56	0.08
Maize silage	202	45.00	0.25

As a result, the three main criteria identified as determinants of biogas substrate selection were summarized in Table 3.8 for comparison.

Table 3.8

Values of Multi-Criteria Analysis

	Effective (yield of biogas, m^3/t)	Environmentally friendly (emissions to be collected in Latvia as kt CO_2 eq./year)	Economically justified (€/m^3 biogas)
Cattle manure	35.0	115.47	0.09
Pig manure	44.0	25.71	0.02
Poultry manure	80.0	4.73	0.03
Sewage sludge	218.0	113.53	0.01
Organic waste	100.0	403.50	-0.74
Wood	35.5	0.00	1.18
Straw	190.0	0.00	0.08
Maize silage	202.0	-6.56	0.25

When the information about the substrates was gathered, it can be observed that the highest efficiency of biogas production is in the production of biogas from sewage sludge as well as maize silage. Straw does not lag behind in the productivity of maize silage biogas. The lowest efficiency is observed in cattle manure and wood, with average efficiency values almost equal. Only slightly higher efficiency is observed in pig manure.

Considering which raw material should preferably be selected for the most environmentally friendly production of biogas, it appears that the most airborne emissions can be prevented by anaerobic fermentation of organic waste. The use of sewage sludge for biogas production as well as the use of cattle manure would provide about 3.4 times less, but still significant emission savings. Equally important is the use of pig manure, but their total methane emissions are lower due to pig numbers. It is also very important to use poultry manure, as their biogas efficiency is only 20 % lower than the efficiency of solid waste, but their environmental impact is less significant due to the quantitative value of this manure. The emissions from biogas maize production in Latvia is the only substrate considered here that generates emissions.

Economically, the most detrimental raw material for biogas production is wood, if purchased as wood chips, but the most advantageous is the use of organic waste, as it not only allows biogas to be produced, but also helps to reduce the cost of waste transfer to landfills.

After the TOPSIS methodology calculations were made a rating was obtained defining which, according to the accepted three criteria (environment, technology, economic), of the given substrates is ranked first and which is ranked the last (8th) for the biogas production in Latvia (Fig.3.6). Pig and poultry manure were ranked in the first two places according to criteria, while straw with pre-treatment was ranked 3rd cattle manure was ranked 4th, but sewage sludge ranked 5th. The last three places are organic waste, corn, and wood, which took a convincing last place in the ranking.

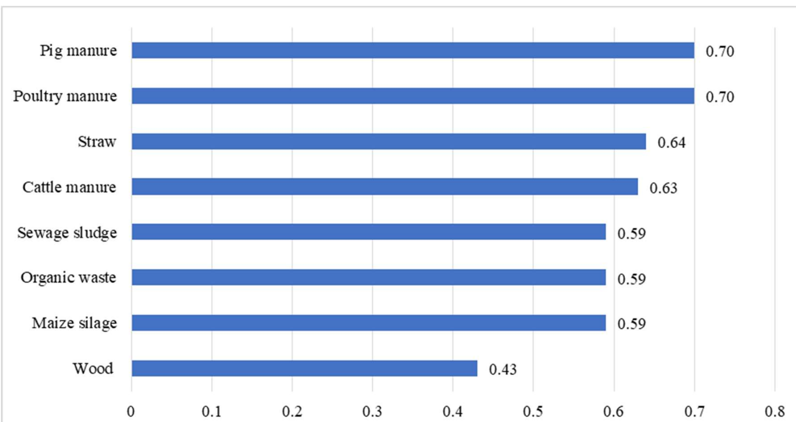

Fig. 3.6. Relative closeness to the ideal solution with TOPSIS method

Fig.3.6 shows that the raw materials are basically divided into 4 groups according to the suitability of the substrate for biogas production:

- group with convincing highest relative closeness to the ideal solution with TOPSIS method, which includes pig and poultry manure and have very similar values,
- group with the second highest relative closeness to the ideal solution with TOPSIS method, which includes straw and cattle manure and have very small difference in values between them,
- group which includes sewage sludge, organic waste and maize silage – feedstocks, the numerical value of which in terms of relative closeness to the ideal solution is nearly the same,
- group which consists with the worst feedstock among the ones considered for the biogas production method is wood.

Results show, that despite the claim that lignocellulose rich plants are not a successful choice for biogas production, straw was the third best substrate for biogas production in Latvia, and cattle manure was in fourth place. Wood was identified as the most unsuccessful choice for biogas feedstock. The penultimate place in the ranking was for specially grown maize for biogas production, which until now has been a popular substrate for agricultural biogas production. Based on the criteria used in the model, the organic waste and sewage sludge are roughly the same as biogas maize in the rating. This work proves that pre-treatment straw can serve as a great substitute for biogas maize.

Evaluation of alternatives for cereal use

In Thesis evaluation of alternatives for cereal use were analyzed as cultivation of cereals has an increasing tendency and emissions from agricultural soils is the largest contributor of agriculture sector.

The analysis of survey results of alternatives considering technology availability and efficiency, cost-effectiveness and sustainability, impact on the environment and climate change, socio-economic aspect - increase in employment and reduced imports for a) each food group, b) pharmaceutical products, c) transport, d) straw product group, are shown in the Fig. 3.10.

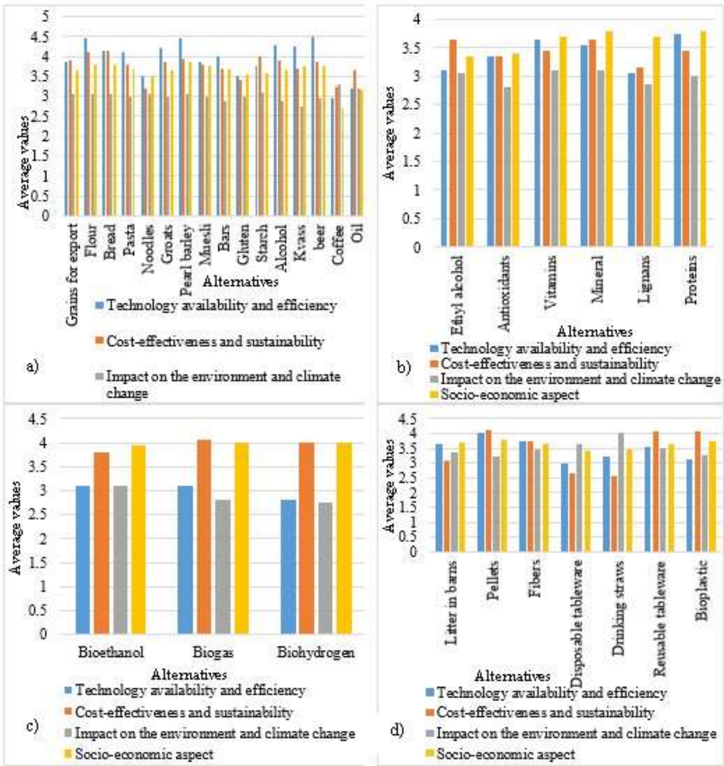

Fig. 3.10. Average rating of respondents for the groups of food, pharmaceutical, straw products, and the transport sector

According to data in Figure 3.10:

a) graph presents the data obtained for the food products represented by sixteen alternatives - grains for export, flour, bread, pasta, noodles, groats, pearl barley, muesli, bars, gluten, starch, alcohol, kvass, beer, coffee and oil,

b) graph shows data obtained from the group of pharmaceutical products represented by six alternatives – ethyl alcohol, antioxidants, vitamins, minerals, lignans and proteins,

c) graph shows the results for the transport products with its three alternatives – bioethanol, biogas and biohydrogen,

d) graph shows the results for the straw product group with its seven alternatives - barn litter, granules, fibers, disposable tableware, drinking straws, reusable tableware, and bioplastics.

The highest assessment of products by criterion according to the survey is presented in Table 3.15.

Table 3.15

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, fibers 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, fibers
Socio-economic aspect – increase in employment and reduced imports	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. 3.11, graphs a),b),c),d) accordingly). MCDA for food (see Fig. 3.11 a)) was represented by 16 alternatives, MCDA for pharmaceuticals (see Fig. 3.11 b)) with its six alternatives, MCDA for products use in the transport sector (see Fig. 3.12 c)) and MCDA for straw products (see Fig. 3.11 d)).

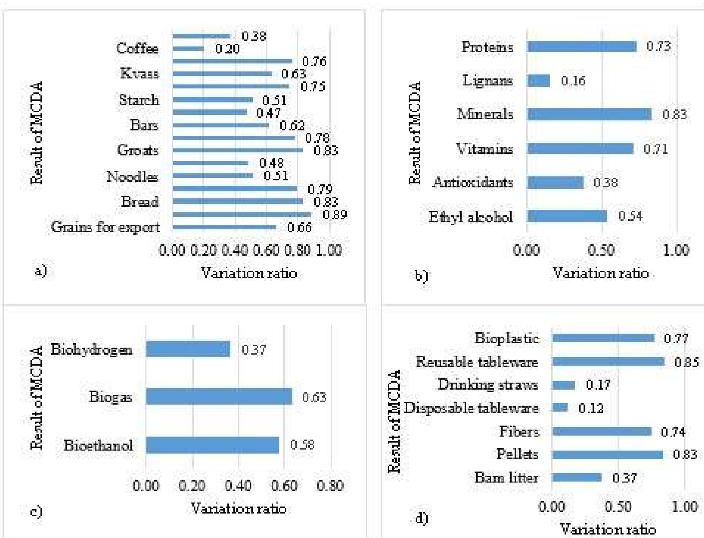

Fig. 3.11. MCDA TOPSIS analysis for the groups of food, pharmaceutical, transport sector and straw products

According to the MCDA TOPSIS analysis, the best alternatives from:

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

Finally, the MCDA TOPSIS method analysis was used to determine which alternative will be the best for each of the four mentioned product groups. In the analysis, four alternatives were selected, one from each product group, which previously had the highest single variation ratio. The summarized results indicated the alternative with the highest added value for each assessed group (Fig. 3.12). 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.

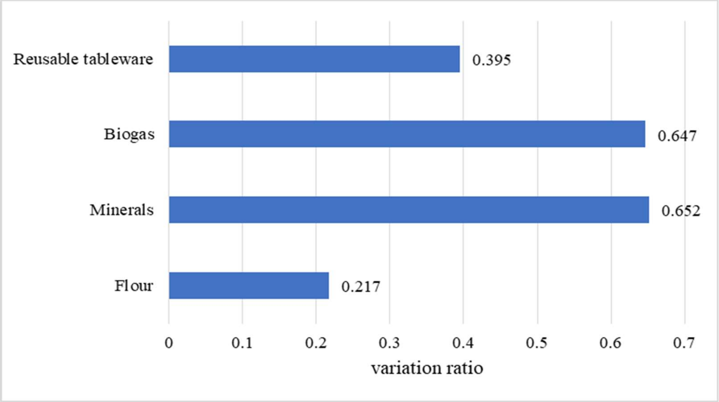

Fig. 3.12. Summary results of the alternatives with the highest added value for each assessed group

3.5. Analysis tool for climate policy ranking and decision-making

The Thesis introduces a method that could be used in addition to existing procedure to evaluate the GHG reduction policies and measures in the agriculture sector, based on the

Delphi method and multi-criteria analysis and taking into account economic, engineering, environmental/climate and social criteria. Criteria weights were determined by sectoral experts. Based on results of the first round of the survey, TOPSIS was used. A normalized and weighted matrix for decision-making in the evaluation of measures to reduce GHG emissions in the agriculture sector are shown in Table 3.12 and Fig. 3.8.

Table 3.12

Weighted Normalised Matrix for Mitigation Measure Evaluation

Measures	Economical	Technical	Climate	Social
Promote and support for precise application of inorganic nitrogen fertilisers	0.075	0.070	0.073	0.022
Support for fertilisation planning	0.088	0.074	0,074	0.023
Requirements for manure storage and spreading	0.063	0.065	0,075	0.022
Promote and support for direct incorporation of organic fertilisers into the soil	0.060	0.064	0.070	0.023
Use of precision agriculture technologies in farms for crop growing to reduce use of nitrogen	0.074	0.068	0.072	0.022
Promote inclusion of leguminous plants in crop rotation for nitrogen fixation	0.073	0.072	0.071	0.024
Support and promote intercropping system in cereal growing	0.065	0.063	0.060	0.021
Support and promote green fallow introduction before winter crop sowing	0.064	0.067	0.057	0.022
Promote organic dairy farming (low emission dairy farming)	0.061	0.071	0.068	0.027
Promote precision cattle feeding approach, including feeding plan development and support good quality use of feed to increase digestibility	0.087	0.079	0.072	0.023
Promote improvement of feed quality for cattle farms	0.078	0.074	0.070	0.024
Promote biogas production	0.060	0.064	0.072	0.024
Promote biogas and biomethane production and biomethane use	0.060	0,062	0,073	0,025
Maintain and modernise amelioration systems on agricultural land	0.070	0.066	0.061	0.023
Promote the conservation of perennial grassland on livestock farms	0.057	0.072	0.068	0.023
Management of nitrate vulnerable territories	0.063	0.067	0.057	0.019
Water and soil protection requirements from pollution-related nitrates	0.059	0.062	0.064	0.022
Create a map of the distribution of peat soils on agricultural land	0.066	0.067	0.070	0.022
Support the development of innovative technologies and solutions to promote resource efficiency, GHG reduction/CO_2 sequestration in agriculture	0.072	0.074	0.074	0.025

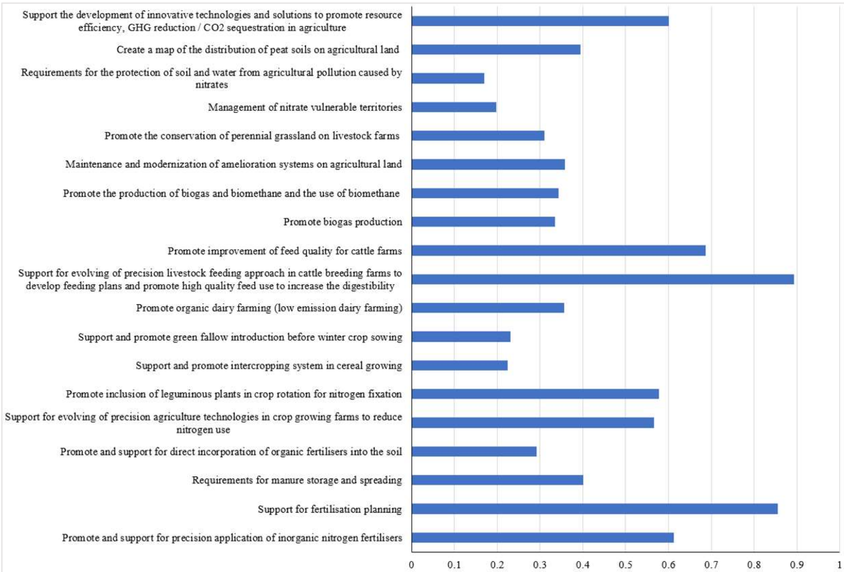

Fig. 3.8. Ranking of measures by TOPSIS

The obtained results showed that considering all criteria, the most effective measures are:

- promotion of precision cattle feeding approach, including the development of feeding plans and use of support good quality feed for increasing the digestibility,
- development of innovative technologies and solutions to promote resource efficiency, and GHG reduction/CO_2 sequestration in agriculture.

The first round of survey displays that in a view of expert's, older farmers do not trust new technologies and would like to work as usual. While young farmers are ready to change and move to smart technologies thereby shifting towards smart agriculture, support for fertilisation planning, promote improvement of feed quality for cattle farms.

Table 3.13

Policies and Measures Grouped by Priority

Priority	Policies and measures				
Leader (0.6–0.9)	Promote precision cattle feeding approach, including development of feeding plans and support for use of good quality feed to increase digestibility	Support for fertilisation planning	Promote improvement of feed quality for cattle farms	Promote and support for precision application of inorganic nitrogen fertilisers	Support the development of innovative technologies and solutions to promote resource efficiency, GHG reduction/CO_2 sequestration
Strong (0.4–0.6)	Promote inclusion of leguminous plants in crop rotation for nitrogen fixation	Use of precision agriculture technologies in farms for crop growth to reduce use of nitrogen	Requirements for manure storage and spreading		
Moderate (0.2–0.4)	Create a map of the distribution of peat soils on agricultural land	Promote organic dairy farming (low emission dairy farming)	Promote biogas and biomethane production and biomethane use	Promote the conservation of perennial grasslands on livestock farms	Support and promote intercropping system in cereal growing
	Maintain and modernise amelioration systems on agricultural land	Support and promote green fallow introduction before winter crop sowing	Promote biogas production	Promote and support for direct incorporation of organic fertilisers into the soil	
Week (0–0.2)	Management of nitrate vulnerable territories	Water and soil protection requirements from pollution related nitrates			

Considering results of MCDA, policies and measures were grouped in order of importance (Table 3.13) and then experts were asked to forecast the main leader of future measures for GHG emission reduction in agriculture sector based on leader measures.

According to the second round of the survey all the involved experts projected that in the future the complex measure "Support for the development of innovative technologies and solutions to promote resource efficiency, and GHG reduction/CO_2 sequestration" will be in the top of all measures in agriculture sector. This measure is projected to be one of the core measures to be developed within the implementation of sustainable and smart agriculture in the future. According to this survey the experts think that this measure could contribute to the reduction of GHG emissions, considering sustainable agricultural management, animal rearing techniques, as well as nutrient management improvement, including precision farming.

In Thesis, the possible mitigation measures in the future for agriculture soil management were analyzed as agricultural soils is the largest contributor of agriculture emissions.

Historical and projected agricultural soils N_2O emissions converted to the common unit of carbon dioxide equivalents (ktCO_2 eq.) as well as mitigation measures of Baltic states, were obtained, and analyzed using comparative analysis method from the publicly available databases [179] and countries reports [148], [158],[159], [180]–[182] for evaluation to find out is there is a move towards climate neutrality in agriculture sectors' sub-sector soil management. Historical and projected emissions in WEM scenario show an increasing tendency for the agricultural soils (Fig.3.9).

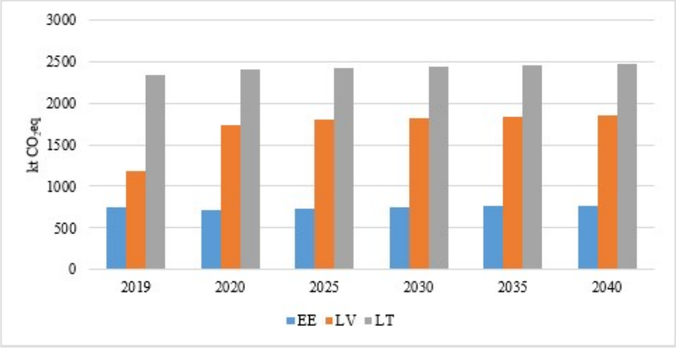

Fig. 3.9. GHG emissions (historical and projected) from agricultural soils [146], [156]–[157]

Based on the literature review [148], [158],[159], [180]–[182] key mitigation measures with estimated mitigation impact in the agriculture sector were summarized in Table 3.14.

Table 3.14

Key Policies and Measures Used in the Agriculture Sector in Baltic Countries [180]–[182]

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 Plar the agriculture 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

It can be seen from the Table 3.14 that for the most key policies and measures, mitigation impact estimation is not available, therefore effect of the mitigation measure cannot be evaluated. This evaluation is essential to understand if key policies and measures ensure planned effect. According to evaluation of key policies and standards for decreasing GHG used 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 [37], there is an upward trend in emissions from agricultural soils. It is therefore necessary to introduce additional mitigation measures in order to move towards sustainable agriculture and climate neutrality. Based on the analysis of mitigation measures in literature [183]–[192] some cost-effective measures for GHG reduction from agricultural soils could be under consideration and detailed analyses of advantages and disadvantages in the future in Baltic countries for example:

- zero-emissions on-farm machinery and equipment;
- low or no – tillage;
- N fixing rotation;
- N-inhibitors on pasture.

3.6. Summary of the obtained results

This section summarizes the results obtained in the Thesis.

1. Regarding the indicators for assessment of the eco-efficiency of agriculture sector, despite the fact that there is available an extensive amount of data at a national level, it is not

easy to compile data that are needed for measuring eco-efficiency performance, especially at the farm level. Overall, the selected indicators show that there is no decoupling between economic growth and GHG emissions during the analysed period, so the steady trend towards eco-efficiency cannot be observed.

2. A tool is proposed with a set of indicators to measure GHG emission reductions in the agriculture sector. A modelling framework was developed for the assessment of GHG emissions mitigation measures based on application of existing agri-environmental indicators. The proposed set of indicators mainly is meant for decision-makers to estimate the agriculture development options and to evaluate the sustainability of the sector, including the production of products with high added value. Agri-environmental indicators based on literature research or defined at national level, have to be introduced for the assessment of GHG reduction measurements at sectoral level.

3. Using the developed carbon balance methodology, it is possible to calculate the impact of biogas production and the impact on the environment as a result of the substrate selection. Such calculations can be applied in any country or company and can be an essential tool for political decision-making, based on quantitative calculations.

The research proves that carrying out carbon balance by the IPCC 2006 methodology based on life cycle analysis for assessment of the impact of biogas production from maize, it is possible to determine the environmental impact in terms of GHG emissions in the atmosphere.

The carbon balance can be further improved by reducing emissions from the agricultural process by growing the substrate, for example, using zero-emission electric off-road machinery for soil tillage, could reduce total biogas maize growing emissions by 43 %. But there are also processes that would not be desirable to reduce emissions, for example, the reduction of off-roads machinery driving frequency in the field – the fertilization process can theoretically be carried out once, but it is usually divided into several stages in order to gradually spread the substances for a favourable plant vegetation process, and not to promote pollution of water due to drainage that leads to erosion.

4. The results showed that pig and poultry manure is the most suitable raw material for biogas production. The use of any waste for energy production is important, but the greatest potential for biogas production from agricultural products are manure and straw. Within the Thesis, the adoption of MCDA is proposed as a suitable solution for evaluating the multi-faceted benefits and/or impacts of different bioresources and technology management scenarios.

5. Key policies and measures within WEM and WAM scenarios for the agriculture sector were used from Latvia's BR4 and NECP to evaluate the top GHG measures for emission reductions to mitigate climate change in the future. A combination of the Delphi method and MCDA allowed to range the measures in order of importance. The results show that in the future, measure "Support for the development of innovative technologies and solutions to promote resource efficiency, and GHG reduction/CO_2 sequestration in agriculture" is essential to move on climate smart agriculture and net-zero emissions balance in 2050. Developing more intelligent/innovative farming will help to improve the quality of products and agriculture sustainability as well as decrease costs. To stimulate innovative technologies for decreasing

GHG emissions and help farmers adapt to climate change a largescale transformative approach, including change in agriculture policy is needed. Usage of the combination of the abovementioned methods in policy planning could support policy makers to achieve better results through already pre-screened GHG mitigation measures for agriculture sector. Additionally, it was concluded that management of agricultural soils is one of the most significant sources of GHG emissions from the agriculture sector in the Baltic countries (50 % of emissions from total agriculture emissions) and growing of cereals shows an increasing trend, with the increasing of the GHG emissions as well. Therefore actions should be taken to decrease emissions from the management of soil already by 2030, to move towards sustainable agriculture and contribute to climate neutrality by 2050. Based on the literature analysis, mitigation measures for management of soils are an essential component to move towards climate neutrality.

As the cultivation of cereals in Baltic states has an increasing tendency also in the future, the study presents the results of a survey which was created in the form of a questionnaire regarding the assessment of use of cereals and straw 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 products 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 of products, the best alternative turned out to be minerals that are important for human health. An additional investigation for the quantitative method application would be useful in future, to evaluate more precisely the use of cereal product not only for farmers but also for more effective decision making in the agriculture sector.

Transition toward the result-based agriculture and climate neutrality can be effectively assessed by using multiple academic methodologies. The Thesis illustrates potential benefit from the proposed integrative decision-making methodology for evaluation of the result-based GHG reduction measures in practice at farm level, in advisory services and in public policy planning (Table 3.16).

Table 3.16.

Overall Scheme of the Proposed Integrative Decision–Making Methodology for Practical Implementation

Methods	**Usage**		
	Farm level	**Advisory services**	**Public policy planning**
Evaluation of eco-efficiency	Demonstration sustainable and climate-friendly farming under the framework of CAP and green procurement	Eliminate bottlenecks on the farm and to recommend the best solution	Quality control schemes under the framework of CAP and regional planning
Carbon balance		To recommend the best crop to be grown from a sustainable farming perspective through workshops, trainings, and consultations.	To identify the best crops to be grown at national level, considering aspects of sustainable agriculture, including climate goals
Ranking of bioresources		To recommend the best bioresources to be grown/used for biogas from a sustainable farming perspective through workshops, trainings, and consultations	To identify the best bioresources to be grown/used for biogas at national level, considering aspects of sustainable agriculture, including climate goals
GHG emission reduction model		To advise farmers on practices to be used to reach the target/indicator within the framework of CAP	To establish specific indicators for the assessment of GHG emission mitigation through legislation to evaluate progress to move towards result-based agriculture and climate neutrality
Tool for ranking climate policies and GHG emission reduction measures and decision-making			Analyze GHG reduction measures in legislation using the MCDA and Delphi approach according to economic, technical, climate and social criteria

To monitor the effectiveness of agricultural policy in relation to its move towards result-based agriculture and climate targets and to achieve accountability and transparency throughout the process, experts involved in preparing national GHG projections should be involved in the process of preparation of the informative report on fulfilment of the commitments of GHG reduction and removal (Informative Report).

The Informative Report should include proposals for additional measures to reduce GHG emissions and increase CO_2 removal, if necessary, but there is no system in place to ensure this task. In this regard, to get quantitative result, the Thesis recommends implementing the integrative decision-making methodology for evaluation of GHG emission reduction measures in the agriculture sector, thus moving towards result-based agriculture sector and climate neutrality. Several ways are proposed of how the methodologies can be used for preparation of the Informative Report taking into account the degree of importance (increase in emissions):

- Detailed analysis each fourth year: A combination of all the methods studied in the Thesis for the ex-ante mitigation measures evaluation;
- Simplified analysis performed each fourth year: A combination of empirical model for eco-efficiency evaluation together with Delphi and MCDA TOPSIS methods could be a very useful approach for the assessment of effectiveness of GHG reduction measures in the agriculture sector;
- Periodic analysis performed every second years A combination of Delphi and MCDA TOPSIS methods used to evaluate the more effective mitigation measures.

A national-level process proposed for the self-assessment of compliance with GHG emission reduction commitments with nationally and internationally determined commitments, science-based is shown in Fig.3.13. To evaluate which kind of review is necessary national experts estimate the main contributors of GHG emissions, the link between the target and the emissions: the higher the emissions, the more detailed analysis is needed.

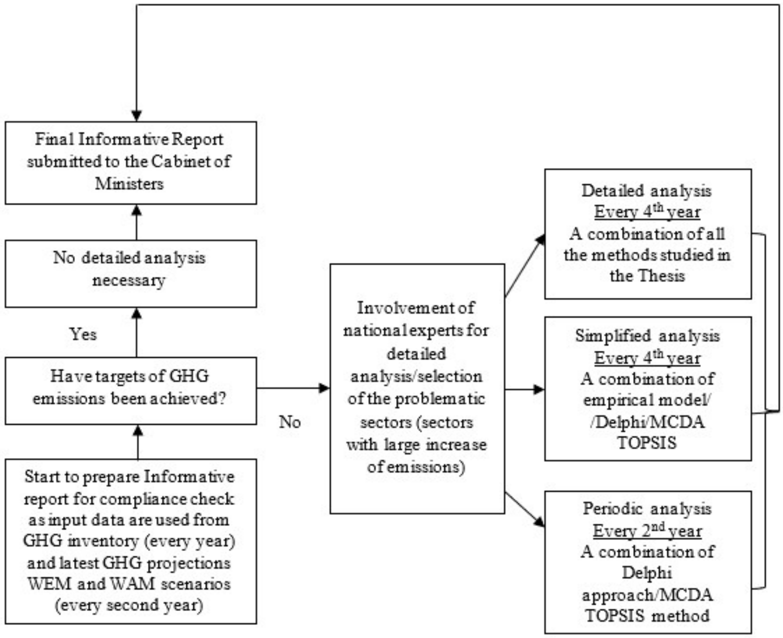

Fig.3.13. Domestic arrangements proposed for the process of the self-assessment of compliance with GHG emission reduction commitments

In essence, such a system and an assessment are very important and essential if a country encounters difficulties in moving towards determined targets and climate neutrality. The use of these methods must be regulated by legislation in order to be actually used.

The following recommendations could be considered for further research based on above mentioned researched topics:

- Agriculture sector is related to other sectors in GHG inventory, for example LULUCF sector, therefore the transition towards result-based agriculture and climate goals both these sectors should be combined; further research is needed for elaboration of carbon farming schemes.
- It is necessary to carry out a more detailed study of the biogas life cycle by sectors included in the GHG inventory.
- To analyse eco-efficiency of the agriculture sector in the future more investigations of activity data are needed in order to understand the potential of mitigation of emissions at farm level, thus getting information using the bottom-up approach.
- Further research is needed to assess the quantitative value of mitigation measure impact in order to evaluate whether the policies have become more targeted and result-based using the proposed integrative decision-making methodology.
- It is recommended to incorporate the methods for the analysis of decision-making in policy planning presented in the Thesis into the regulatory framework.

CONCLUSIONS

The main findings of the Thesis are as follows:

- The international assessment report of the European Environment Agency on projected GHG emissions in the Latvian agricultural sector displays that despite the large number of GHG reduction measures (approximately twenty), they do not have a significant reduction effect, as the GHG emission projections show an increasing trend until 2050. Such assessments suggest that the current framework for the choice of GHG reduction measures needs to be improved, thus contributing to the achievement of climate goals.
- There are certain aspects that follow from the EU recent initiatives which must be in place for fundamental transformation to result-based agriculture sector in relation to climate targets, including practical reduction measures determined by achievable indicators, socio-economic and financial restructuring, significant use of research and development potential.
- It can be concluded that a systematic approach is needed that combines experts' analysis and ability to assess the agriculture sector's progress towards climate goals more broadly and in depth, as well as the consequences and potential benefits at system level. This dissertation is the first step in laying the foundations for such a system.
- The empirical model can help to assess the eco-efficiency of the agriculture sector, thus helping to assess whether additional actions are needed.
- The proposed GHG emissions reduction model/tool can assist stakeholders in decision- making regarding production of agricultural products with high added value taking into account GHG emissions mitigation measurement indicators.
- The carbon balance analysis of biogas production from maize proves and determines the possible environmental impact in terms of GHG emissions on atmosphere.
- Bioresources ranking with application of the multi-criteria decision analysis using TOPSIS methodology is a significant approach for sustainable application of resources for biogas production and use of biogas at technological level.
- Using a combination of the Delphi approach and MCDA TOPSIS method in policy planning could supply decision-makers with better data through predefined GHG mitigation measures.
- The Thesis proposes an overall scheme for implementation an integrative methodology for practical use in policy planning. The mandate for such a scheme could be set out in Climate Law.
- Application of integrative methodology including sectoral indicators, carbon balance analysis, and a decision-making analysis tool for GHG emissions mitigation measures promotes moving towards result-based agriculture.

REFERENCES

[1] Gancone A., et al. Latvia's National GHG Inventory report 1990–2019 to the UNFCCC. Riga: VARAM, 2021.

[2] Latvia's National Energy and Climate plan 2021–2030. Riga: Cabinet of Ministers, 2020.

[3] COM (2021) 555, Proposal for a Regulation amending Regulation (EU) 2018/842 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement.

[4] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL Sustainable Carbon Cycles. COM (2021) 800 final [Online] Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0800&qid=1640000660456 [Accessed: 22.02.2022].

[5] IPCC, 2018: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

[6] PARIS AGREEMENT. United Nations. 2015. [Online] Available: https://unfccc.int/sites/default/files/english_paris_agreement.pdf [Accessed: 02.02.2022].

[7] Submission by Latvia and the European Commission on Behalf of the European Union and its Member States. Intended Nationally Determined Contribution of the EU and its Member States. Riga, 6 March 2015. [Online] Available: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Italy%20First/LV-03-06-EU%20INDC.pdf [Accessed: 22.02.2022].

[8] Communication from the commission to the European parliament, the European council, the council, the European economic and social committee and the committee of the regions, The European Green Deal. COM/2019/640 final. [Online] Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN [Accessed: 02.02.2022].

[9] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. COM/2020/381 final [Online] Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381 [Accessed: 02.02.2022]

[10] COM (2020) 80 final, Proposal for a Regulation of the European Parliament and of the Council establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law). [Online] Available: https://eur-lex.europa.eu/legal content/EN/TXT/?qid=1585761577648&uri=CELEX:52020PC0080 [Accessed: 02.02.2022].

[11] COM (2020) 98 final, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A new Circular Economy Action Plan [Online] Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN [Accessed:03.01.2022].

[12] CAP Specific objectives by country: [Online] Available https://ec.europa.eu/info/food-farming-fisheries/farming/facts-andfigures/performance-agricultural-policy/agriculture-country/cap-specific-objectives-country_en [Accessed: 12.02.2022].

[13] COM (2018) 392 final 2018/0216 (COD) Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing rules on support for strategic plans to be drawn up by Member States under the Common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulation (EU) No 1305/2013 of the European Parliament and of the Council and Regulation (EU) No 1307/2013 of the European Parliament and of the Council. Brussels, 1.6.2018. [Online] Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A392%3AFIN [Accessed: 02.02.2021].

[14] SUBMISSION BY GERMANY AND THE EUROPEAN COMMISSION ON BEHALF OF THE EUROPEAN UNION AND ITS MEMBER STATES. The update of the nationally determined contribution of the European Union and its Member States. Berlin, 17 December 2020. [Online] Available: https://unfccc.int/NDCREG [Accessed: 02.03.2021].

[15] REGULATION (EU) 2018/842 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013. [Online] Available: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex:32018R0842 [Accessed: 02.03.2021].

[16] COM (2021) 555, Proposal for a Regulation amending Regulation (EU) 2018/842 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement. [Online] Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A555%3AFIN [Accessed: 02.03.2021].

[17] COM/2021/554 final, Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulations (EU) 2018/841 as regards the scope, simplifying the compliance rules, setting out the targets of the Member States for 2030 and committing to the collective achievement of climate neutrality by 2035 in the land use, forestry and agriculture sector, and (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A555%3AFIN [Accessed: 02.03.2021].

[18] Latvia's Adaptation plan to climate change for the period until 2030. Riga: Cabinet of Ministers, 2019. [Online]. Available: https://likumi.lv/ta/id/308330-par-latvijas-pielagosanas-klimata-parmainam-planu-laika-posmam-lidz-2030-gadam [Accessed:24.01.2021].

[19] Strategy of Latvia for the Achievement of Climate Neutrality until 2050. Riga: Cabinet of Ministers, 2020. [Online]. Available: https://unfccc.int/documents/267179. [Accessed:01.02.2022].

[20] REGULATION (EU) 2018/1999 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council. [Online]. Available: https://eurlex.europa.eu/legalcontent/EN/TXT/HTML/?uri=CELEX:32018R1999&from=LV [Accessed:12.11.2021].

[21] MoA. Latvia’s Common Agricultural Policy Strategic plan for 2023–2027 project. 2022.

[22] Informatīvais ziņojums “Par Latvijas Kopējās lauksaimniecības politikas stratēģisko plānu2023.-2027.gadam”.2022.[Online].

Available:https://www.zm.gov.lv/public/files/CMS_Static_Page_Doc/00/00/02/21/39/KLPSP_projekts_20220118_SFC2021_izdruka_no_20220318.pdf [Accessed:19.02.2022].
[23] Informative report to Cabinet of Ministers "Meeting commitments to reduce greenhouse gas emissions and sequester carbon dioxide" Riga. 2022.
[24] Latvia's Ministry of Agriculture. Latvian agriculture 2020. [Online]. Available: https://www.zm.gov.lv/public/files/CMS_Static_Page_Doc/00/00/01/89/03/2020_lauksaimniecibas_gada_zinojums1.pdf [Accessed: 13.05.2020].
[25] AGRICULTURE OF LATVIA, 2020. Collection of Statistics. Central Statistical bureau. Riga. 2020.
[26] Agriculture in Latvia. Collection of Statistical Data. Rīga (2020) 80 p. [Online]. Available: https://www.csb.gov.lv/lv/statistika/statistikas-temas/lauksaimnieciba/augkopiba/meklet-tema/424-latvijas-lauksaimnieciba-2020 [Accessed:15.06.2021].
[27] FCCC/CP/2013/10/Add.3. UNFCCC Decision 24/CP.19. [Online]. Available: https://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf [Accessed:12.05.2020].
[28] FCCC/CP/2010/7/Add.2. Decision. 9/CP.16.National communications from Parties included in Annex I to the Convention. 2011. [Online]. Available: https://unfccc.int/sites/default/files/resource/docs/2010/cop16/eng/07a02.pdf [Accessed:17.04.2020].
[29] EEA. Guidelines for reporting on greenhouse gas policies and measures under Regulation (EU) No 2018/1999. 2021.
[30] Commission Implementing Regulation (EU) 2020/1208 of 7 August 2020 on structure, format, submission processes and review of information reported by Member States pursuant to Regulation (EU) 2018/1999 of the European Parliament and of the Council and repealing Commission Implementing Regulation (EU) No 749/2014. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32020R1208 [Accessed:14.05.2021].
[31] LEGMC. Summary of GHG inventory 2021. [Online]. Available: https://videscentrs.lvgmc.lv/lapas/zinojums-par-klimatu [Accessed:19.07.2021].
[32] IPCC. National Greenhouse Gas Inventories. 2006. [Online]. Available: https://www.ipccnggip.iges.or.jp/public/2006gl/ [Accessed:12.03.2019]
[33] Project "Development of the national system for greenhouse gas (GHG) inventory and reporting on policies, measures, and projections". [Online]. Available http://www.varam.gov.lv/eng/fondi/EEA_Norv/european_economic_area_financial_mechanism_programme__national climate_policy/?doc=18431: [Accessed: 23.05.2020].
[34] AGRICULTURE OF LATVIA, 2019. Collection of Statistics. Central Statistical bureau. Riga. 2019.
[35] European Commission decision 2017/1471 amended decision 2013/162/EU to revise member States' AEAs for 2017–2020. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017D1471&from=PL [Accessed: 12.09.2019].
[36] Dimbiere A., Gancone A., etl. Latvia' s 2021 report to EC policies measures and projections. Riga. 2020.
[37] ETC/CME Eionet Report/6/2021, Agricultural climate mitigation policies and measures.
[38] Heiner, J., Holzapfel, S., 2016. Results-based approaches in agriculture: what is the potential?
[39] Janus, H. (2014). Real innovation or second-best solution? First experiences from results-based aid for fiscal decentralisation in Ghana and Tanzania (Discussion Paper 3/2014). Bonn: German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE).; Pearson, M. (2011). Results based aid and results based financing: What are they? Have they delivered results? London, UK: HLSP Institute.

[40] O'Brien, T., & Kanbur, R. (2014). The operational dimensions of results-based financing. Public Administration and Development, 34(5), 345–358.
[41] Birdsall, N., Savedoff, W. D., Mahgoub, A., & Vyborny, K. (2011). Cash on delivery: A new approach to foreign aid.[Online]Available: http://www.cgdev.org/files/1424603_file_CashDelivery_FINAL.pdf[Accessed:02.03.2020]
[42] Gelb, A., & Hashmi, N. (2014). Anatomy of PforR. [Online] Available: http://www.cgdev.org/sites/default/ files/PforR%20Presentation%201.23.14.pptx [Accessed: 19.08.2019].
[43] Keijzer, N., & Janus, H. (2014). Linking results-based aid and capacity development support: Conceptual and practical challenges (Discussion Paper 25/2014). Bonn: German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE).
[44] David Wuepper, Robert Huber. 2021. Comparing effectiveness and return on investment of action- and results-based agri-environmental payments in Switzerland.
[45] COWI, Ecologic Institute and IEEP (2021) Technical Guidance Handbook - setting up and implementing result-based carbon farming mechanisms in the EU Report to the European Commission, DG Climate Action, under Contract No. CLIMA/C.3/ETU/2018/007. COWI, Kongens Lyngby.
[46] COMMISSION STAFF WORKING DOCUMENT Sustainable carbon cycles - Carbon farming. SWD(2021) 450 final [Online] Available: https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX:52021SC0450 [Accessed: 02.03.2022].
[47] COMMISSION STAFF WORKING DOCUMENT Sustainable carbon cycles for a 2050 climate-neutral EU Technical Assessment Accompanying the Communication from the Commission to the European Parliament and the Council Sustainable Carbon Cycles. SWD(2021) 451 final [Online] Available: https://op.europa.eu/en/publication-detail/-/publication/d86883c0-5d8e-11ec-9c6c-01aa75ed71a1/language-en [Accessed: 02.03.2022].
[48] Koskela, M., Vehmas, J., Defining eco-efficiency: A case study on the Finnish forest industry. Bus. Strateg. Environ. 2012;21:546–566
[49] Ramli N, Munisamy S. Eco-efficiency in greenhouse emissions among manufacturing industries: A range adjusted measure. Econ. Model 2015;47:219–227.
[50] Gordon, T.J., The Delphi method. Futures Research Methodology. V2.0. AC/UNU Millenium Project 2003;3.
[51] Rowe, W., Expert Opinions in Forecasting. Role of the Delphi Technique. In: Armstrong (Ed.): Principles of Forecasting: A Handbook of Researchers and Practitioners, Boston: Kluwer Academic Publishers; 2001.
[52] Sarkis, J., Cordeiro, J., Ecological modernization in the electrical utility industry: An application of a bads–goods DEA model of ecological and technical efficiency. Eur. J. Oper. Res. 2012;219:386–395.
[53] Rebitzer, G., Hunkeler, D., The future of Life Cycle Assessment. The International Journal of Life Cycle Assessment 2005;10(5):305–308.
[54] Lyrstedt, F., Measuring Eco-efficiency by a LCC/LCA Ratio An Evaluation of its Applicability A case study at ABB Master of Science Thesis in the Master Degree Programme. International Project Management. 2005.
[55] Bell, W. Foundations of Futures Studies: Human Science for a new era; 2000.
[56] Koskela M. Measuring eco-efficiency in the Finnish forest industry using public data. Journal of Cleaner Production 2015;98:316−327.
[57] European Commission. 2018. 2050 long-term strategy. Going climate neutral by 2050 [Online]. Available: https://ec.europa.eu/clima/policies/strategies/2050_en [Accessed:26.07.2020].

[58] European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions. A policy framework for Climate and Energy in the period from 2020 to 2030, 2014. [Online]. Available: https://ec.europa.eu/clima/policies/strategies/2030_en [Accessed:20.04.2017].
[59] Bereiter, B., Eggleston, S., Schmitt, J., Nehrbass-Ahles, C., Stocker, T. F., Fischer, H., Kipfstuhl, S., Chappellaz, J. Revision of the EPICA Dome C CO2 record from 800 to 600 kyr before present. Geophysical Research Letters 2015:42(2):542– 549.
[60] Meyer, A.K.P., Ehimen, E.A. & Holm-Nielsen, J.B. 2018. Future European biogas: Animal manure, straw and grass potentials for a sustainable European biogas production. Biomass and Bioenergy 111, 154–164. https://doi.org/10.1016/j.biombioe.2017.05.013
[61] European Commission. Communication from the Commission to the European parliament, the European council, the council, the European economic and social committee, the committee of the regions and the European investment bank. A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, 2018. [Online]. Available: https://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=CELEX:52018DC0773. [Accessed 15.05.2020]
[62] Chen, X.Y., Vinh-Thang, H., Ramirez, A.A., Rodrigue, D. & Kaliaguine, S. 2015. Membrane gas separation technologies for biogas upgrading. RSC Advances 5, 24399–24448.
[63] Li., Y., Wen, Z., Li, J., Cai, L. & Wang, H. 2019. Feasibility of utilizing by-product biogas in breweries after being decarbonized for refrigeration chiller and related primary energy efficiency analysis. Sustainable Energy Technologies and Assessments 31, 390–400.
[64] Timonen, K., Sinkko, T., Luostarinen, S., Tampio, E. & Joensuu, K. 2019. LCA of anaerobic digestion: Emission allocation for energy and digestate. Journal of Cleaner Production 235, 1567–1579.
[65] Bumbiere, K., Gancone, A., Pubule, J., Kirsanovs, V., Vasarevicius, S. & Blumberga, D. 2020. Ranking of Bioresources for Biogas Production. Environmental and Climate Technologies 24(1), 368–377.
[66] Krištof, K. & Gaduš, J. 2018. Effect of alternative sources of input substrates on biogas production and its quality from anaerobic digestion by using wet fermentation. Agronomy Research 16(3), 769–783.
[67] Melvere, M., Ivanovs, K., Pubule, J. & Blumberga, D. 2017. Use of round goby (Neogobius melanostomus) processing waste in bioeconomy. Energy Procedia 128, 484–490.
[68] Mano Esteves, E.M., Naranjo Herrera, A.M., Pecanha Esteves, V.P. & Vaz Morgado, C.R. 2019. Life cycle assessment of manure biogas production: A review. Journal of Cleaner Production 219, 411–423.
[69] Meiramkulova, K., Bayanov, A., Ivanova, T., Havrland, B., Kára, J. & Hanzlíková, I. 2018. Effect of different compositions on anaerobic co-digestion of cattle manure and agro-industrial by-products. Agronomy Research 16(1), 176–187.
[70] Muizniece, I., Zihare, L., Pubule, J. & Blumberga, D. 2019. Circular Economy and Bioeconomy Interaction Development as Future for Rural Regions. Case Study of Aizkraukle Region in Latvia. Environmental and Climate Technologies 23, 129–146.
[71] Mehryar, E., Ding, W.M., Hemmat, A., Hassan, M., Bi, J.H., Huang, H.Y. & Kafashan, J. 2017. Anaerobic co-digestion of oil refinery wastewater and chicken manure to produce biogas, and kinetic parameters determination in batch reactors. Agronomy Research 15(5), 1983–1996.
[72] Ugwu, S.N., Biscoff, R.K. & Enweremadu, C.C. 2020. A meta-analysis of iron-based additives on enhancements of biogas yields during anaerobic digestion of organic wastes. Journal of Cleaner Production 269, 122449.

[73] Sauthoff, S., Musshoff, O., Danne, M. & Anastassiadis, F. 2016. Sugar beet as a biogas substrate? A discrete choice experiment for the design of substrate supply contracts for German farmers. Biomass and Bioenergy 90, 163–172.
[74] Siddique, M.N.I. & Wahid, Z.A. 2018. Achievements and perspectives of anaerobic co-digestion: A review. Journal of Cleaner Production 194, 359–371.
[75] Schulz, V.S., Munz, S., Stolzenburg, K., Hartung, J., Weisenburger, S., Mastel, K., Möller, K., Claupein, W. & Graeff-Hönninger, S. 2018. Biomass and biogas yield of maize (Zea mays l.) grown under artificial shading. Agriculture 8.
[76] Pimentel, D. 2003. Ethanol fuels: Energy balance, economics, and environmental impacts are negative. Natural Resources Research 12, 127–134. h
[77] Gowik, U.& Westhoff, P. 2011. The Path from C3 to C4 photosynthesis. Plant Physiology 155, 56–63.
[78] Crafts-Brandner, S.J. & Salvucci, M.E. 2002. Sensitivity of photosynthesis in a C4 plant, maize, to heat stress. Plant Physiology 129, 1773–1780.
[79] Arodudu, O.T., Helming, K., Voinov, A. & Wiggering, H. 2017. Integrating agronomic factors into energy efficiency assessment of agro-bioenergy production – A case study of ethanol and biogas production from maize feedstock. Applied Energy 198, 426–439.
[80] Patzek, T.W. 2004. Thermodynamics of the corn-ethanol biofuel cycle, CRC. Critical Reviews in Plant Sciences 23, 519–567.
[81] Cavinato, C., Fatone, F., Bolzonella, D. & Pavan, P. 2010. Thermophilic anaerobic co-digestion of cattle manure with agro-wastes and energy crops: Comparison of pilot and full scale experiences. Bioresource Technology 101, 545–550.
[82] Shah, F.A., Mahmood, Q., Rashid, N., Pervez, A., Raja, I.A. & Shah, M.M. 2015. Co-digestion, pretreatment and digester design for enhanced methanogenesis. Renewable & Sustainable Energy Reviews 42, 627–642.
[83] Murphy, F., Devlin, G. & McDonnell, K. 2014. Forest biomass supply chains in Ireland: A life cycle assessment of GHG emissions and primary energy balances. Applied Energy 116, 1–8.
[84] Muench, S. & Guenther, E. 2013. A systematic review of bioenergy life cycle assessments. Applied Energy 112, 257–273.
[85] Cherubini, F. 2010. GHG balances of bioenergy systems - Overview of key steps in the production chain and methodological concerns. Renewable Energy 35, 1565–1573.
[86] Scarlat N., Dallemand J. F., Fahl F. Biogas: Developments and perspectives in Europe. Renewable Energy 2018:129 (A):457–472.
[87] Yu Q., Liu R., Li K., Ma R. A review of crop straw pretreatment methods for biogas production by anaerobic digestion in China. Renewable and Sustainable Energy Reviews 2019:107:51–58.
[88] Timonen, K., Sinkko, T., Luostarinen, S., Tampio, E., Joensuu, K. LCA of anaerobic digestion: Emission allocation for energy and digestate. Journal of Cleaner Production 2019:235:1567–1579.
[89] Karklins, A. Biogas production in Latvia. Possibilities of obaining and using biomethane [Online]. Available: http://www.sam.gov.lv/images/modules/items/PDF/item_6133_6_LBA_biometans_SM_06.2016.pdf [Accessed: 28.07.2029]
[90] BiogasAction – New developments in Latvia. [Online]. Available: https://www.fedarene.org/biogasaction-new-developments-latvia-23060] [Accessed: 27.06.2020].
[91] Development of biogas in Latvia [Online]. Available: http://latvijasbiogaze.lv/index.php?c=3 [Accessed 15.05.2019].

[92] Central Statistical Bureau of Latvia. Renewable energy consumption in 2017 [Online]. Available: https://www.csb.gov.lv/lv/statistika/statistikas-temas/vide-energetika/energetika/meklet-tema/2407-atjaunigoenergoresursu-paterins-2017-gada [Accessed:15.05.2018].
[93] Blumberga, D., Veidenbergs, I., Romagnoli, F., Rochas, C., Žandeckis, A. Bioenergy Technologies, Riga: RTU, 2011.
[94] European Environmental Agency. EMEP/EEA air pollutant emission inventory guidebook 2019. Biological treatment of waste – anaerobic digestion at biogas facilities [Online]. Available: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 [Accessed 15.05.2015].
[95] Li, K., Liu, R., Sun, C. A review of methane production from agricultural residues in China. Renewable and Sustainable Energy Reviews 2016:54:857–865.
[96] Ministry of Environment and Regional development of Latvia. Land policy plan for 2016–2020. [Online]. Available: http://www.varam.gov.lv/in_site/tools/download.php?file=files/text/Sab_lidzdaliba/sab_apsp/VARAM_Zemes_politi kas_plans_211116.pdf [Accessed:27.03.2021].
[97] Prochnow, A., Heiermann, M., Plöchl, M., Linke, B., Idler, C., Amon, T., Hobbs, P. J. Bioenergy from permanent grassland – A review: 1. Biogas. Bioresource Technology 2009:100:21:4931–4944.
[98] Chiumenti, A., Borso, F., Limina, S. Dry anaerobic digestion of cow manure and agricultural products in a full-scale plant: Efficiency and comparison with wet fermentation. Waste Management 2018:71:704–710.
[99] Latvian Renewable Energy federation. Biogas energy [Online]. Available: https://www.laef.lv/en/biogas// [Accessed 15.05.2019].
[100] Putri, D., Saputro, R., Budiyono B. Biogas Production from Cow Manure. International Journal of Renewable Energy Development 2012:1:2:61–64.
[101] Meyer, A. K. P., Ehimen, E. A., Holm-Nielsen, J. B. Future European biogas: Animal manure, straw and grass potentials for a sustainable European biogas production. Biomass and Bioenergy 2018:111:154–164.
[102] Mano Esteves E. M., Naranjo Herrera A. M., Peçanha Esteves V. P., Morgado C. R. V. Life cycle assessment of manure biogas production: A review. Journal of Cleaner Production 219:411–423.
[103] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
[104] Food and agriculture organization of the United Nations. CLIMATE-SMART AGRICULTURE Sourcebook. Rome: FAO, 2013
[105] "Climate-Smart" Agriculture Policies, Practices and Financing for Food Security, Adaptation and Mitigation Food and Agriculture Organization of the United Nations. Rome: FAO, 2010.
[106] Lipper, L., et al. Climate-smart agriculture for food security. Nature Climate Change 2014:4:1068–1072.
[107] Amin, A., et al. Climate Smart Agriculture: an approach for sustainable food security. Agricultural Research Communication 2015:2(3):13–21.
[108] Lipper, L., Zilberman, D. A Short History of the Evolution of the Climate Smart Agriculture Approach and Its Links to Climate Change and Sustainable Agriculture Debates. In Lipper L., McCarthy N., Zilberman D., Asfaw S., Branca G. (eds) Climate Smart Agriculture. Natural Resource Management and Policy 2018:52:13–30.

[109] Climate Smart Agriculture [Online]. Available: https://www.iaea.org/topics/climate-smartagriculture [Accessed: 22.03.2021].
[110] Campbell, B. M., et al. Sustainable intensification: What is its role in climate smart agriculture? Current Opinion in Environmental Sustainability 2014:8:39–43.
[111] Pagliacci, F., et al. Drivers of farmers' adoption and continuation of climate-smart agricultural practices. A study from northeastern Italy. Science of The Total Environment 2020:710:136345.
[112] Climate-Smart Agriculture. World Bank [Online]. Available: https://www.worldbank.org/en/topic/climate-smart-agriculture [Accessed: 22.03.2021].
[113] Long, T. B., Blok, V., Coninx, I. The diffusion of climate-smart agricultural innovations: Systems level factors that inhibit sustainable entrepreneurial action. Journal of Cleaner Production 2019:232:993–1004.
[114] Tesfai, M., et al. Transition towards bio-based economy in small-scale agriculture in Sub-Saharan Africa through sustainable intensification. The Bioeconomy Approach. Constraints and Opportunities for Sustainable Development. London: Routledge, 2020.
[115] Senyolo, M. P., et al. How the characteristics of innovations impact their adoption: an exploration of climate-smart agricultural innovations in South Africa. Journal of Cleaner Production 2018:172:3825–3840.
[116] Khatri-Chhetri, A., et al. Stakeholders prioritization of climate-smart agriculture interventions: Evaluation of a framework. Agricultural Systems 2019:174:23–31.
[117] Long, T. B., Blok, V., Coninx, I. Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy. Journal of Cleaner Production 2016:112(1):9–21.
[118] Smith P., Martino D., etl. Greenhouse gas mitigation in agriculture. 2008.
[119] Domingo J., De Miguel E., Hurtado B., Metayer N., Bochu J.L., Pointereau P. Measures at farm level to reduce greenhouse gas emissions from EU agriculture, 2014. [online] [12.03.2019] Available at: http://www.europarl.europa.eu/RegData/etudes/note/join/2014/513997/IPOLAGRI_NT%282014%29513997_EN.pdf 13.
[120] Asgedom, H., Kebreab E. Beneficial management practices and mitigation of greenhouse gas emissions in the agriculture of the Canadian Prairie: a review. Agronomy Sustainable Development, vol. 31, 2011, pp. 433-451.
[121] LLU. monografija. Siltumnīcefekta gāzu emisiju samzināšanas iespējas ar klimtam draudzīgu lauksaimniecību un mežsaimniecību Latvijā. Jelgava. 2018.
[122] Popluga, D, Naglis-Liepa, K., Latvia University of Agriculture. EVALUATION OF MEASURES FOR MITIGATION OF GREENHOUSE GAS EMISSIONS SUITABLE FOR LATVIAN AGRICULTURE [Online] Available: https://www.tf.llu.lv/conference/proceedings2015/Papers/095_Popluga.pdf [Accessed: 14.06.2021].
[123] Lenerts, A., Popluga, D., Rivza, P., SELECTION OF GREENHOUSE GAS EMISSION-REDUCING MEASURES WITH ANALYTICAL HIERARCHY PROCESS APPROACH: A CASE STUDY FROM LATVIAN CROP PRODUCTION SECTOR. [Online] Available: https://llufb.llu.lv/conference/economic_science_rural/2017/Latvia_ESRD_44_2017-267-273.pdf [Accessed:28.03.2021].
[124] Blumberga, D., Energoefektivitāte. Rīga: Apgāds "Pētergailis," 1996.
[125] Seltman, H. J. Experimental Design and Analysis. 2018.
[126] Mukaka, M. M., "Statistics Corner: A Guide to Appropriate Use of Correlation Coefficient," Malawi Med. J., vol. 24, no. 3, pp. 69–71, 2012, [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/23638278/

[127] Montgomery, D. C., Peck, E. A. Introduction to linear regression analysis,5th ed. New Jersey, USA: John Wiley & Sons, 2012
[128] Uyanık, G. K., Güler, N. "A Study on Multiple Linear Regression Analysis," Procedia– Soc. Behav. Sci., vol. 106, pp. 234–240, 2013, doi: 10.1016/j.sbspro.2013.12.027.
[129] Turcott Cervantes et al., 2018. Using indicators as a tool to evaluate municipal solid waste management: A critical review. DOI:10.1016/j.wasman.2018.08.046
[130] Rametsteiner et al., 2011. Sustainability indicator development—Science or political negotiation? DOI:10.1016/j.ecolind.2009.06.009
[131] Ercin and Hoekstra, 2012. United Nations Educational, Scientific and Cultural Organization (UNESCO). Carbon and water footprints : Concepts, methodologies and policy responses
[132] Ernst & Young Accountants LLP Transparency Report 2011 complies with the European Union's 8th Company Law Directive, the Dutch Decree on the Supervision of Audit Firms (Besluit toezicht accountantsorganisaties) and it further includes, where relevant, the guidance on Transparency reports issued by the Netherlands Institute of Chartered Accountants. This report covers the period 1 July 2010 - 30 June 2011.
[133] Karklins, A. Calculation methods and standards for the use of soil treatment and fertilizers.
[134] Liu, Z., Gao, J., Gao, F., Liu, P., Zhao, B. & Zhang, J. 2019. Late harvest improves yield and nitrogen utilization efficiency of summer maize. Field Crops Research 232, 88–94. https://doi.org/10.1016/j.fcr.2018.12.014
[135] Ericsson, N., Nordberg, Å. & Berglund, M. 2020. Biogas plant management decision support - Atemperature and time-dependent dynamic methane emission model for digestate storages.Bioresource Technology Reports 11, 100454.
[136] Blumberga, D., Dzene, I., Al Seadi, T., Rutz, D., Prassl, H., Kottner, M., Finsterwalder, T.,Volk, S. & Janssen, R. 2010. Biogas HANDBOOK. [Online] Available:https://docplayer.org/69439281-Dblumberga-i-dzene-t-al-sedi-d-rucs-h-prasls-m-ketners-t-finstervalders-s-folka-r-jansensbiogaze-rokasgramata.html. [Accessed:15.09.2021].
[137] Blumberga, D., Veidenbergs, I., Romagnoli, F., Rochas, C., Žandeckis, A. Bioenergy Technologies, Riga: RTU, 2011.
[138] Scarlat, N., Dallemand, J.F. & Fahl, F. 2018. Biogas: Developments and perspectives in Europe. Renewable Energy 129, 457–472.
[139] Kumar et al., 2017. A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. March 2017Renewable and Sustainable Energy Reviews 69:596-609. DOI:10.1016/j.rser.2016.11.191
[140] TOPSIS method algorithm. | Download Scientific Diagram. [Online]. Available https://www.researchgate.net/figure/TOPSIS-methodalgorithm_fig4_253953426 [Accessed: 13.05.2019].
[141] Roszkowska E. MULTI-CRITERIA DECISION-MAKING MODELS BY APPLYING THE TOPSIS METHOD TO CRISP AND INTERVAL DATA. 2011.
[142] Berglund Odhner P., Sárvári Horváth I., H. Mohseni Kabir M., Schabbauer A. Biogas from lignocellulosic biomass, 2012 [Online]. [Accessed 15.05.2019]. http://www.sgc.se/ckfinder/userfiles/files/SGC247.pdf.
[143] Tong, H., Tong, Y. W., Peng, Y. H. A comparative life cycle assessment on mono- and co-digestion of food waste and sewage sludge. Energy Procedia 2019:158:4166–4171.
[144] Gancone, A., et al. Latvia's National GHG Inventory report 1990 – 2017 to the UNFCCC. Riga: VARAM, 2019.
[145] Dick, S., et al. The Delphi Method Research Strategy in Studies of Information Systems. Communications of the Association for Information Systems 2015:37:31–63.

[146] Harold, A. L., Turoff, M., Helmer, O. The Delphi Method Techniques and Applications. Boston: Addison-Wesley, 2002.
[147] Green, R.A. The Delphi Technique in Educational Research. Education Theory and Practice, Educational Research, Research Methods 2014:4(2).
[148] Gancone, A., et al. Latvia's forth Biennial Report to the UNFCCC. Riga: VARAM, 2019.
[149] Pubule, J., et al. Finding an optimal solution for biowaste management in the Baltic States. Journal of Cleaner.
[150] Hwang, C. L., Yoon K. Multiple Attribute Decision Making. Springer, 1981. https://doi.org/10.1007/978-3-642-48318-9
[151] Tzeng, G. H., Huang, J. J. Multiple Attribute Decision Making: Methods and Applications. Chapman and Hall/CRC, 2011.
[152] Bumbiere, K., et al. Carbon balance of biogas production from maize in Latvian conditions. Agronomy Research 2021:19(1):687–697.
[153] UNFCCC. Report on the technical review of the fourth biennial report of Latvia. Bonn: UNFCCC, 2020.
[154] Popluga D., Naglis-Liepa K. Evaluation of measures for mitigation of greenhouse gas emissions suitable for Latvian agriculture. Engineering for Rural Development 2015:584–589
[155] Bumbiere, K., et al. Ranking of Bioresources for Biogas Production. Environmental and Climate Technologies 2020:24(1):368–377.
[156] Bumbiere, K., Pubule J., Blumberga D. What Will Be the Future of Biogas Sector? Environmental and Climate Technologies 2021:25(1):295–305.
[157] Naglis-Liepa K., Popluga D. Integrated impact assessment of agricultural GHG abatement measures.2018. Proceedings of the 2018 International Conference "Economic science for rural development" 2018:49:77–83.
[158] Estonia Fourth Biennial Report under the United Nations Framework Convention on Climate Change.2019.
[159] Lithuania Fourth Biennial Report under the United Nations Framework Convention on Climate Change.2020.
[160] Duchene, O., Celette F., Ryan R. M., DeHaan R. L., Crews E. T., Davida C. 2019. Integrating multipurpose perennial grains crops in Western European farming systems. Agriculture, Ecosystems & Environment.
[161] Hayes, R.C., Newell, M. T., DeHaan, L.R., Murphy K.M., Crane S., Norton M.R., Wade L.J., Newberry M., Fahim M., Jones S.S., Cox T.S., Larkin P.J. 2012. Perennial cereal crops: An initial evaluation of wheat derivatives. Field Crops Research, pp. 68-89
[162] Marti, A., Bock E., J., Pagani, A., M., Ismail, B., Seetharaman, K. 2016. Structural characterization of proteins in wheat flour doughs enriched with intermediate wheatgrass (Thinopyrum intermedium) flour. Food Chemistry, pp. 994-1002.
[163] Gancone, A., et al. Latvia's National GHG Inventory report 1990 – 2014 to the UNFCCC. Riga: VARAM, 2016.
[164] LEGMC database. [Online] Available: http://parissrv.lvgmc.lv/#viewType=home_view [Accessed: 15.03.2016].
[165] European Commission. Development of agri-environmental indicators for monitoring the integration of environmental concerns into the common agricultural policy; 2006. [Online] Available: http: www.eea.europa.eu/policy-documents/development-of-agri-environemntal-indicators. [Accessed: 15.05.2016].
[166] European Environmental Agency. Agriculture and environment in EU-15-the IRENA indication report; 2005. [Online] Available: http://www.eea.europa.eu/publications/eea_report_2005_6 [Accessed: 15.05.2016].

[167] Ramli, N., Munisamy, S. Eco-efficiency in greenhouse emissions among manufacturing industries: A range adjusted measure. Econ. Model 2015;47:219–227.
[168] Gordon, TJ. The Delphi method. Futures Research Methodology. V2.0. AC/UNU Millenium Project 2003;3.
[169] Rowe, Wright. Expert Opinions in Forecasting. Role of the Delphi Technique. In: Armstrong (Ed.): Principles of Forecasting: A Handbook of Researchers and Practitioners, Boston: Kluwer Academic Publishers; 2001
[170] Brown, S., Beecher, N. & Carpenter, A. 2010. Calculator tool for determining greenhouse gas emissions for biosolids processing and end use. Environmental Science & Technology 44, 9509–9515.
[171] Tambone, F., Orzi, V., Zilio, M. & Adani, F. 2019. Measuring the organic amendment properties of the liquid fraction of digestate.
[172] Slepetiene, A., Volungevicius, J., Jurgutis, L., Liaudanskiene, I., Amaleviciute-Volunge, K., Slepetys, J. & Ceseviciene, J. 2020. The potential of digestate as a biofertilizer in eroded soils of Lithuania. Waste Management 102, 441–451.
[173] Naglis-Liepa, K. & Pelse, M. 2014. Biogas production from agricultural raw materials. https://llufb.llu.lv/conference/economic_science_rural/2014/ESRD_34_2014_Productions - 172-179.pdf
[174] Iocoli, G.A., Zabaloy, M.C., Pasdevicelli, G. & Gómez, M.A. 2019. Use of biogas digestates obtained by anaerobic digestion and co-digestion as fertilizers: Characterization, soil biological activity and growth dynamic of Lactuca sativa L. Science of the Total Environment 647, 11–19.
[175] Verdi, L., Kuikman, P.J., Orlandini, S., Mancini, M., Napoli, M. & Dalla Marta, A. 2019. Does the use of digestate to replace mineral fertilizers have less emissions of N2O and NH 3? Agricultural and Forest Meteorology 269–270, 112–118.
[176] Central Statistic Bureau, CSB database, (n.d.). [Online] Available: https://www.csb.gov.lv/lv/statistika/db [Accessed: 05.01.2021]
[177] Advertisements portal [Online]. Available: https://www.ss.com/ [Accessed 15.05.2020].
[178] Tariffs for municipal waste [Online]. Available: http://www.getlini.lv/en/private-clients [Accessed 15.05.2020].
[179] Eurostat database (https://ec.europa.eu/eurostat/data/database).
[180] FCCC/TRR.4/LVA. Report on the technical review of the fourth biennial report of Latvia.2019.
[181] FCCC/TRR.4/EST. Report on the technical review of the fourth biennial report of Estonia.2020
[182] FCCC/TRR.4/LTU. Report on the technical review of the fourth biennial report of Lithuania.2020.
[183] Popluga, D., Kreišmane, Dz. 2019. SEG emisijas samazinoši pasākumi.
[184] McKinsey & Company. 2020. Agriculture and climate change. Reducing emissions through improved farming practices.
[185] Ricardo Muñoz et al., "Estimation of the lifespan of agricultural tractors using a diffusion model at the aggregate level," Ciencia e investigación agrarian, December 2012, Volume 39, Number 3, pp. 557–62
[186] Samuelson, K.L. et al., The 2015 New Mexico State and Texas Tech University survey, Journal of Animal Science, June 2016, Volume 94, Number 6, pp. 2648–63, ncbi.nlm.nih.gov; Harmsen, "Non-CO2 greenhouse gas mitigation"; Hristov et al., "Mitigation of greenhouse gas emissions"; "Animal production and health," FAO, accessed July 2019, fao.org; Jiafa Luo et al., "Nitrous oxide and greenhouse gas emissions from grazed pastures as affected by the use of nitrification inhibitor and restricted grazing regime,"

Science of the Total Environment, Volume 465, November 1, 2013, pp. 107–114, sciencedirect.com.
[187] Pedro Pellegrini et al., “Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution,” Proceedings of the National Academy of Sciences, February 2018, Volume 115, Number 10, researchgate.net.
[188] Controlled- and slow-release fertilisers, IHS Markit, June 2018, ihsmarkit.com; Wilfried Winiwarter, “Reducing nitrous oxide emissions from agriculture: Review on options and costs,” June 9, 2015, pure.iiasa.ac. At; David Kanter et al., “Reducing nitrogen pollution while decreasing farmers’ costs and increasing fertiliser industry profits,” Journal of Environmental Quality, March 2015, Volume 44, Number 2, researchgate.net.
[189] LLU. 2019. “Latvijas lauksaimniecības siltumnīcefekta gāzu un amonjaka emisiju, kā arī CO2 piesaistes (aramzemēs un zālājos) robežsamazinājuma izmaksu līkņu (MACC) pielāgošana izmantošanai lauksaimniecības, vides un klimata politikas veidošanā”
[190] MacLeod, M. et al. (2015-08-01), “Cost-Effectiveness of Greenhouse Gas Mitigation Measures for Agriculture: A Literature Review”, OECD Food, Agriculture and Fisheries Papers, No. 89, OECD Publishing, Paris. http://dx.doi.org/10.1787/5jrvvkq900vj-en
[191] Hoglund-Isaksson et al., 2010, EU low carbon roadmap 2050: Potentials and costs for mitigation of non-CO2 greenhouse gas emissions
[192] Stéphane, De Cara, Pierre-Alain, Jayet. Marginal abatement costs of greenhouse gas emissions from European agriculture, cost-effectiveness, and the EU non-ETS Burden Sharing Agreement. 2010.

PUBLICATIONS ARISING FROM THIS THESIS

EVALUATION OF AGRICULTURE ECO-EFFICIENCY IN LATVIA

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 128 (2017) 309–315

Energy Procedia

www.elsevier.com/locate/procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2017, 10–12 May 2017, Riga, Latvia

Evaluation of agriculture eco-efficiency in Latvia

Agita Gancone*, Jelena Pubule, Marika Rosa, Dagnija Blumberga

Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV–1048, Latvia

Abstract

Agriculture is the second most significant source of greenhouse gas (GHG) emissions, with approximately 24 % of Latvia's total GHG emissions in 2014. Emissions from agricultural soils contributed major share of the total emissions – 59.6 %, enteric fermentation emissions was second largest source – 32 %. The share of manure management emissions was evaluated as 7.5 % of total emissions in the sector, remaining 0.9 % of emissions refer to liming and urea application. GHG emissions increased in 2014 by 3.3 % comparing to 2013 due to increase of cattle, sheep and fur animal numbers. Statistics also showed increase of synthetic N fertilizer consumption approximately by 4.6 %, sown area by 0.3 % and lime application to soils 42.9 % [1]. Bearing in mind significant share of agricultural emissions in total GHG emissions in Latvia and the growing emission trend the additional attention is necessary for evaluation of impacts of agriculture on the environment.

The purpose of this study is to explore indicators for assessing eco-efficiency in the Latvian agriculture sector. First the paper describes methods which can be used for measuring eco-efficiency, second availability of activity data and third, presents calculations of selected indicators for eco-efficiencies.

Peer review statement - Peer-review under responsibility of the scientific committee of the International Scientific Conference "Environmental and Climate Technologies".

Keywords: GHG emissions; ecoefficiency; agriculture; indicators

* Corresponding author.
E-mail address: agancone@inbox.lv

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer review statement - Peer-review under responsibility of the scientific committee of the International Scientific Conference "Environmental and Climate Technologies".
10.1016/j.egypro.2017.08.318

1. Introduction

The literature does not provide a specific definition of eco-efficiency. In general, eco-efficiency could be explained by the production of products with higher added value and less impact on the environment. As it is stated by Koskela and Vehmas [2] eco-efficiency definitions can be presented in five groups [2]. The first group of definitions refers to the expression "more from less", then secondly and thirdly eco-efficiency is considered as the ratio between economic and environmental output. More specifically, the second group emphasis on the productiveness: the production of additional value added with less impact on the environment. The fourth group describes eco-efficiency as a control strategy, but the fifth group of the definitions provides more specific guidance of control strategy in the enterprise level for improving eco-efficiency. The main concept of the eco-efficiency is to help companies and governments become more sustainable [3−9].

There are three types of methods for measuring eco-efficiency: first the single-ratio model of environmental impact/economic output. Model accepts and combines environmental impacts in one account though life cycle analysis. This single-ratio model is used to analyse the efficiency of products and technologies, as well as is easy to understand it. Secondly, replacement of the numerator with other mixed indicators, such as ecological footprint, energy and material flow analysis indicators. This mentioned method by evaluating the environmental performance of the system can be used. Thirdly, efficiency assessed by models such as the Range Adjusted Measure model can be used. These models give and explain advisable and unacceptable outputs in the process of production [10]. A wide range of methods for assessment of eco-efficiency, for example, Delphi method [11, 12], Data envelopment analysis (DEA) [13], Life Cycle Assessment (LCA) [14] jointly with Life Cost Cycle (LCC) [15] analysis and others are described in literature [16, 17]. It is essential to analyse availability of the activity data in both farm and national level to apply these methods for assessment of eco-efficiency. Different kind of information is available to get insights in ways how to measure the impact on environment. There are two substantial questions which need to take into account for measuring eco-efficiency − how to measure and what kind of possible indicators can be used for measurements. Examples of environmental and economic performance measurement indicators which were mentioned in the literature are summarised in the Table 1 [18].

Table 1. Environmental and economic performance measurement indicators for agriculture sector.

Environmental and economic performance	Indicators
Inputs for the production	Water use, thsd m^3 Energy use or consumption, GJ/TJ Raw material consumption, thsd tonnes Land use, thsd. hectares
Outputs as emissions groups	GHG emissions, kt CO_2 eq Emissions to water, tonnes Emissions air, tonnes, kt
Environmental impact	Climate change Biodiversity Smell Use of synthetic fertilizers, kt nitrogen Fossil fuels, GJ/TJ
Economic indicators	Gross domestic product, thsd. EURO / % Employees, thsd Value added, milj EURO Amount of production, kt/thsd tons
Resource use intensity	Water intensity, m^3 /GDP Energy intensity, TJ/GDP Land use intensity, thsd. hectares/GDP
Environmental impact intensity	CO_2 intensity, kt CO_2 eq/GDP CH_4 intensity, kt CO_2 eq/GDP N_2O intensity, kt CO_2 eq/GDP

2. Methodology

Based on the different literature studies it is possible to identify eco-efficiency indicators for agriculture sector at company and state level. There are four main steps which characterize eco-efficiency performance process presented in Fig. 1. The analysis of eco-efficiency indicators is done step by step.

Fig. 1. Eco-efficiency performance process.

As economic indicator the Gross domestic product of the sector, and for measuring of the environmental indicators – emissions were used. The selection of indicators depends from the ways where they will be used. It is significant to set generally applicable indicators that can be used by all interested groups (for example, farms, government, other institutions) and therefore clearly described measurement methods are needed. Based on the literature studies many of indicators were highlighted (for example, inputs for the production, energy intensity (MJ/GDP), land use (thsd hectares / GDP), water intensity (m^3 / GDP) and environmental impact: climate change, biodiversity, smell), but for detailed analysis of eco-efficiency only energy use, inputs for production, production of agricultural products, GHG emission groups and environmental impact on climate change were used for this study. Regression analysis is used for evaluation of relationship between GHG emissions and production of agricultural products, and other parameters. Firstly, the regression analysis is used to identify the strength of the effect that the independent variable have on a dependent variable.

Regression analysis also is used to predict trends of dependent values. To calculate linear regression, the equation $y = a + bx$ is used. When selecting the model for the analysis, another important consideration is the model fitting and estimation how independent variable explains variance of the model (typically expressed as R^2).

3. Results

As it was mentioned previously the important precondition to evaluate eco-efficiency indicators is availability of activity data therefore investigations in this field have been carried out. It was found out that data from many institutions are available in different dimensions, but in this study mainly data from the Central statistical bureau of Latvia (CSB) and Latvian Environment, Geology and Meteorology Centre (LEGMC) were analysed as they are main data sources for official reports by Latvia to different international institutions. CSB is the key coordinator and performer of the official statistic in the country while the LEGMC collects environmental information, in collaboration with other institutions prepares different annual reports including reports on GHG and air emissions, carries out environmental monitoring and informs the society on the environmental situation. The database of CSB [19] contains different kind of data, including economic and environment field. Mostly data is presented on the country and regional level. For this study mainly activity data regarding economic activities of agriculture for 2000–2014, but in some cases from 1990, in country level were used. Data on GHG emissions were taken from national annual GHG inventories reported in the framework of the United Nations Convention on Climate Change [1]. Other activity data were taken from databases of LEGMC. It was concluded that full data set on farm level regarding agricultural emissions is not available. In some cases data are not disaggregated enough.

Results of the calculation of chosen indicators for eco-efficiency evaluation in agriculture sector are summarised in the Fig. 2−Fig. 5.

First, energy intensity was analysed (Fig. 2) where noticeable data fluctuations can be observed, which can be explained with lack of data correlation between fuel consumption and GDP. Linear graph shows amount of fuel used in sector corresponding with sector GDP. For example, in 2001 compared with 2000 amount of fuel used in sector increased by 9.3 % similar with GDP that increased by 8.9 % in the same time period, but in 2001−2002 amount of fuel used in sector decreased by 7.1 % and GDP sharply decreased by 13.5 %. Similar situation can be seen through whole time series. Most significant deflection from trend-line is in the year 2008 (−9.3 %) and 2009 (−13.3 %) due to inconsistent changes in fuel consumption and GDP. While in 2007−2008 fuel consumption dropped by 16.3 %, for GDP it was only −6.6 %, similar situation with 2007−2009 when fuel consumption decreased by 10.5 %, while GDP increased by 5.3 %. In these years, Latvia went through economic crisis that left noticeable impact in all sectors not only agriculture. Also, one of the most used fuels in agriculture sector is diesel oil (~60 %−80 % from the total consumption) which has large statistical difference due to illegal import from neighbouring countries. Regression analysis shows that in average energy intensity every year decreases by 71.9 MJ/GDP thsd EUR. When economic situation was stabilized in the country, energy intensity stabilized as well. Energy intensity trend is negative linear trend that means that energy saving technologies are used.

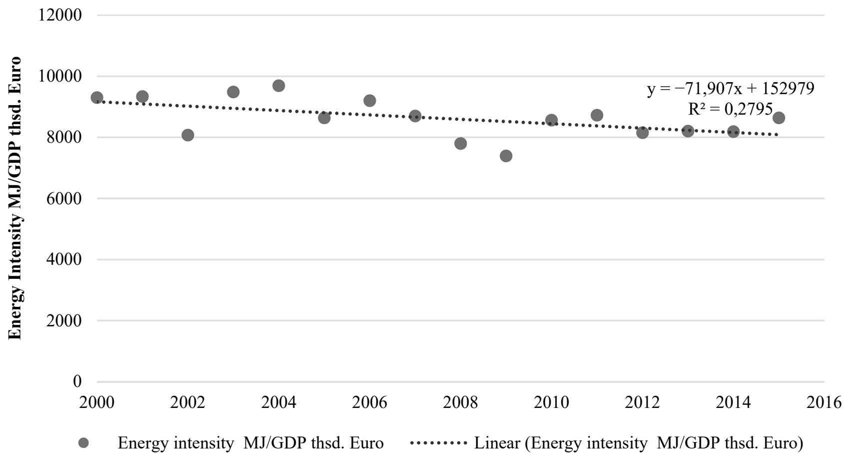

Fig. 2. Energy intensity MJ/GDP.

Secondly CH_4 and N_2O emission intensity in the sector were analysed (Fig. 3 and Fig. 4). A strong correlation between methane emissions and livestock production − output of meat and milk have been observed. Regression analysis shows that production of milk will increase methane emissions more than meat production. Methane emissions will increase average by 1.52 kt CO_2 eq on each thsd t milk produced, but methane emissions will increase average by 0.16 kt CO_2 eq on each thsd t meat produced. While in the crop production a weak correlation between the production of grain, potatoes and vegetables and the amount of nitrogen oxide emissions have been noticeable. The reason for that could be the fact that total nitrous oxide emissions include emissions from management of organic soils and pasture, which are not directly related to the crop production. Essential elements in production of crops are consumption of nitrogen fertilizers as well as use of organic fertilizers which more accurately show relationships between the crop output and emissions of nitrogen oxides.

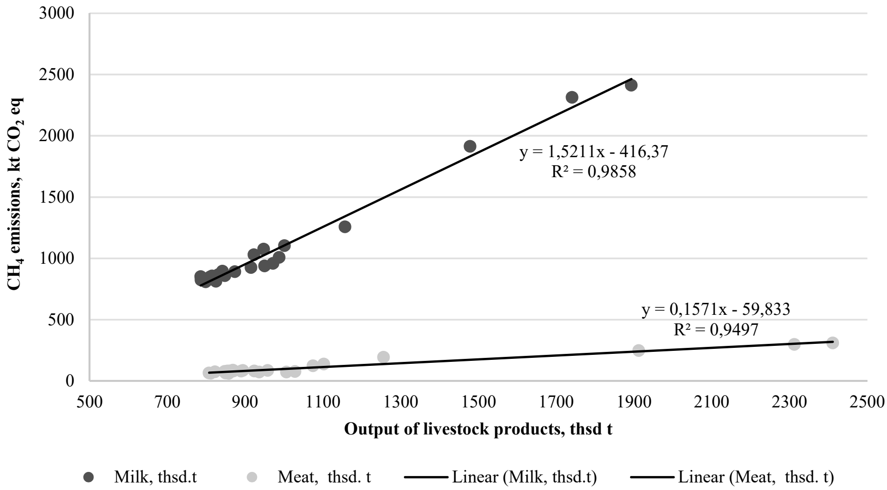

Fig. 3. Link between CH_4 emissions (kt CO_2 eq) and meat and milk production.

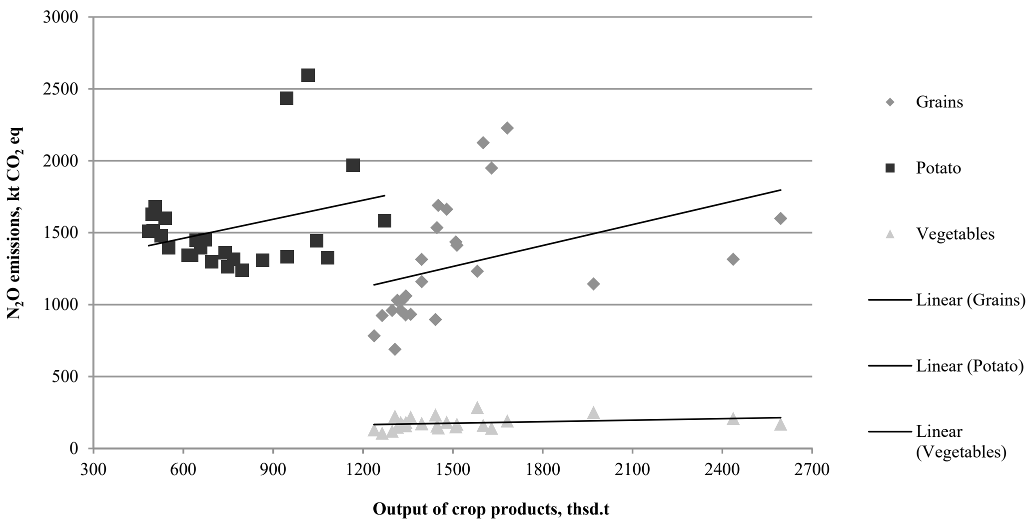

Fig. 4. Link between crop production and N_2O emissions (kt CO_2 eq).

Overall analysis of the eco-efficiency in the agriculture sector is presented in the Fig. 5, where total GHG emissions, GDP, used energy, use of agricultural area, crop production and other parameters in the sector are included. As it can been seen from the Fig. 5, GHG emissions in the agriculture sector (~28 %) and GDP (~48 %) have growing tendency from 2000 till 2014, but it is important to point out, that GHG emissions mainly have been increasing due to the application of N fertilizers to soils and management of organic soils. As well as use of N fertilizers has been weakly correlating with crop yields − it means that consumption of N fertilizers is growing, but crop yields do not grow accordingly in the period used for analysis, especially for 2009−2011. This graph explains the weak relationship between the nitrogen oxide emissions and production of crop products mentioned above. It can be seen that there is a significant increase in use of nitrogen fertilizers, but crop output growth is ambiguous, perhaps it could be linked to the impact of agro-meteorological conditions.

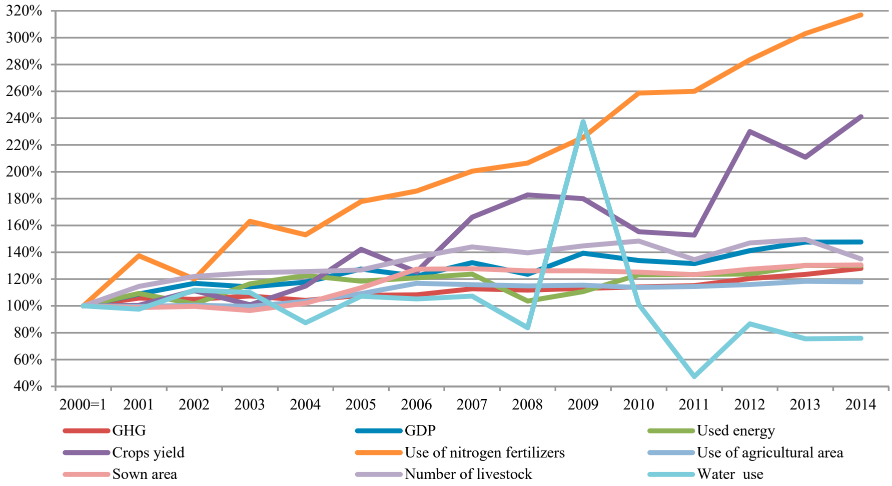

Fig. 5. Changes (%) of main indicators in agriculture for 2000–2014 (2000 = 1).

Water use data [20] shows that it has a strong tendency to slowly decrease, and it can be explained by more efficient use of water. Some outliers of data (for years 2009 and 2011) seems to be caused by insufficient quality of data. Therefore future investigations is needed for evaluation of water use data.

4. Conclusions

The goal of the study was to evaluate indicators which could be used for measurement of the eco-efficiency in Latvia's agriculture sector based on different kind of published information. Despite the fact that there is available an extensive amount of data it is not easy to compile data which are needed for measuring eco-efficiency performance. Selected indicators show that no GHG emission decoupling (decoupling between gross domestic product (GDP) growth and GHG emissions increase implies a simultaneous growth and development of national economy and reduction of GHG emissions) from economic growth in agriculture sector has been observed. In other words economic and environment output grow together, but at the same time emissions are growing more slowly. Taking into account results of the study more investigations of activity data are needed to understand potential mitigation of emissions in the future and analyse eco-efficiency of the sector by using different methods. It is necessary to analyse farm level data (from biggest crop production farms) in more detail level thus getting information from bottom up approach is required.

Acknowledgements

The work has been supported by the National Research program "Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)".

References

[1] LEGMC, 2016: Latvia's National Inventory under the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and Regulation (EU) No 525/2013 for 1990−2014.
[2] Koskela M, Vehmas J. Defining eco-efficiency: A case study on the Finnish forest industry. Bus. Strateg. Environ. 2012;21:546–566.
[3] Dace E, Blumberga D. How do 28 European Union Member States perform in agricultural greenhouse gas emissions? It depends on what we look at: Application of the multi-criteria analysis. Ecological Indicators 2016;71:352−358.
[4] Dace E, Muizniece I, Blumberga A, Kaczala F.. Searching for solutions to mitigate greenhouse gas emissions by agricultural policy decisions—Application of system dynamics modeling for the case of Latvia. Science of the Total Environment 2015;527:80−90.
[5] Falasca S, Pitta-Alvarez S, Ulberich A. Developing an Agro-Ecological Zoning Model for Tumbleweed (Salsola kali), as Energy Crop in Drylands of Argentina. Environmental and Climate Technologies 2017;18:17−32.
[6] Bajcinovci B. Environment Quality: Impact From Traffic, Power Plant and Land Morphology, a Case Study of Prishtina. Environmental and Climate Technologies 2017;19:65−74.
[7] Muizniece I, Dace E, Blumberga D. Dynamic modeling of the environmental and economic aspects of bio-resources from agricultural and forestry wastes. Procedia Earth and Planetary Science 2015;15:806−812.
[8] Pubule J, Gancone A, Rosa M, Blumberga D. Sectoral Greenhouse Gas Emission Mitigation Possibilities. Why Broad Spectrum of Indicators is Applied. Energy Procedia 2017;113:377−381.
[9] Timma L, Zoss T, Blumberga D. Life after the financial crisis. Energy intensity and energy use decomposition on sectorial level in Latvia. Applied Energy 2016;162:1586−1592.
[10] Ramli N, Munisamy S. Eco-efficiency in greenhouse emissions among manufacturing industries: A range adjusted measure. Econ. Model 2015;47:219–227.
[11] Gordon TJ. The Delphi method. Futures Research Methodology. V2.0. AC/UNU Millenium Project 2003;3.
[12] Rowe, Wright. Expert Opinions in Forecasting. Role of the Delphi Technique. In: Armstrong (Ed.): Principles of Forecasting: A Handbook of Researchers and Practitioners, Boston: Kluwer Academic Publishers; 2001.
[13] Sarkis J, Cordeiro J. Ecological modernization in the electrical utility industry: An application of a bads–goods DEA model of ecological and technical efficiency. Eur. J. Oper. Res. 2012;219:386–395.
[14] Rebitzer G, Hunkeler D. The future of Life Cycle Assessment. The International Journal of Life Cycle Assessment 2005;10(5):305–308.
[15] Lyrstedt F. Measuring Eco-efficiency by a LCC/LCA Ratio An Evaluation of its Applicability A case study at ABB Master of Science Thesis in the Master Degree Programme. International Project Management; 2005.
[16] Bell W. Foundations of Futures Studies: Human Science for a new era; 2000.
[17] Cilinskis E, Blumberga A, Blumberga D. Analysis of non-ETS sector goals using climate change indicators. Energy Procedia 2016;95:98−103.
[18] Koskela M. Measuring eco-efficiency in the Finnish forest industry using public data. Journal of Cleaner Production 2015;98:316−327.
[19] CSB database. Available: http://www.csb.gov.lv/en/dati/data-23959.html.
[20] LEGMC database. Available: http://parissrv.lvgmc.lv/#viewType=home_view

SECTORAL GREENHOUSE GAS EMISSION MITIGATION POSSIBILITIES.

WHY BROAD SPECTRUM OF INDICATORS IS APPLIED

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 113 (2017) 377 – 381

Energy Procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2016, 12–14 October 2016, Riga, Latvia

Sectoral greenhouse gas emission mitigation possibilities. Why broad spectrum of indicators is applied

Jelena Pubule*, Agita Gancone, Marika Rosa, Dagnija Blumberga

Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV–1048, Latvia

Abstract

Greenhouse gas (GHG) emissions from agriculture account for 10 % of total greenhouse gas emissions in the European Union (EU). Mitigation potential of agriculture can be obtained from enhancement of avoidance and reduction of GHG emissions through management of land and livestock. The share of emissions from agriculture in different EU member states (EU MS) varies considerably in accordance with the significance and comparative magnitude of the agricultural sector. On a regular basis, EU MS data are collated regarding progress in development of agriculture and emission mitigation, using different indicators. The aim of this study is to analyse existing indicators used for the evaluation of impacts of agriculture on environment and propose a tool for assessment of GHG emissions mitigation measurements and assist stakeholders in decision making regarding production of agricultural products with a high added value. The research gives insight on how to achieve climate friendly agriculture. The proposed indicators can be used to evaluate GHG emissions mitigation measurements in agriculture.

Peer-review under responsibility of the scientific committee of the International Scientific Conference "Environmental and Climate Technologies".

Keywords: agriculture sector; GHG emission mitigation; agri-environmental indicators

* Corresponding author. Tel.: +371 67089923; fax: +371 67089923.
E-mail address: jelena.pubule@rtu.lv

Peer-review under responsibility of the scientific committee of the International Scientific Conference "Environmental and Climate Technologies".
doi:10.1016/j.egypro.2017.04.015

1. Introduction

Agriculture plays a key role in mitigating climate change. Half of the earth's surface has been used for agricultural purposes [1, 2]. GHG emissions from agriculture amount to 10 % of total GHG emissions in the EU according to Annex I Party GHG Inventory Submissions for 2016 [3].

The share of emissions from agriculture in 2014 in different EU MS considerably varies depending on the significance and comparative magnitude of the agricultural sector (32.2 % in Ireland, 20.3 % in Lithuania, 24.0 % in Latvia and 3.0 % in Malta) [3]. 45 % of total EU agriculture emissions are accounted for by France (19 %), Germany (15 %) and the United Kingdom (11 %) in 2012 [4]. In comparison, Bulgaria, Finland, Lithuania, Croatia, Slovakia and Latvia account for about 1 % each of total EU-28 agriculture emissions in 2012 [4]. Total GHG emissions from agriculture declined by 21 % from 1990. It must be considered that from 1990 till 2000, emissions decreased by 16 %, but from 2001 until 2011 only by 7 %. The main reduction of GHG emissions are attributed to increase of productivity, decrease in livestock, development and implementation of agricultural and environmental policies [6]. During the research indicators used for evaluation of impacts of agriculture on the environment [7–9] were analysed.

2. Methodology

The objective of this research is to offer a tool to assess and collate GHG emission mitigation measures of agriculture.

The basic concept of the research is shown in Fig. 1.

The main aim of this study is to analyse existing indicators used for evaluation of impacts of agriculture on environment, to propose a tool with a set of indicators for assessment of GHG emissions mitigation measurements, and to assist stakeholders in decision making regarding production of agricultural products with a high added value.

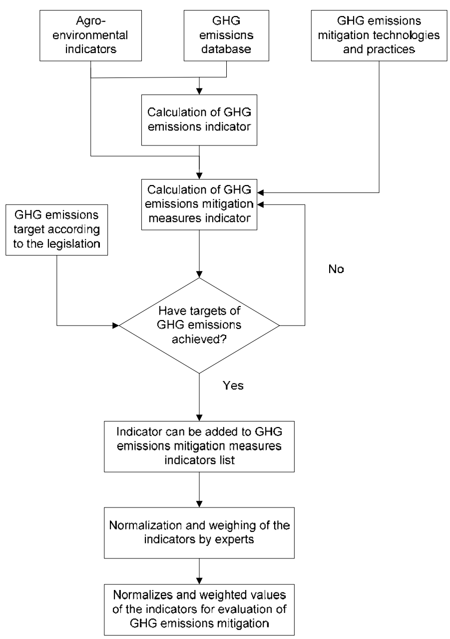

Fig. 1. Methodological framework of selection and evaluation of indicators.

3. Results

3.1. Indicators used for evaluation of GHG emissions from agriculture

The European Commission has developed 35 agri-environmental indicators for assessing impacts of agriculture [10, 11]. From these indicators 11 indicators are set as relevant to the assessment of agriculture in relation to climate change and air quality: mineral fertilizer consumption, energy use, cropping/livestock patterns, farm management practices — manure management, atmospheric emissions of ammonia from agriculture, emissions of methane (CH_4) and nitrous oxide (N_2O) from agriculture, share of agriculture in GHG emissions, area under agri-environment support, regional levels of good farming practice, regional levels of environmental targets and production of renewable energy.

Table 1. Agri-environmental indicators.

Indicator	**Parameter, unit**
Mineral fertilizer consumption	Application rates (kg/ha) of N and P
Energy use	Total direct energy use at farm level in KgOE per ha per year
Cropping/livestock patterns	Share (%) of main agricultural land types (on total UAA. Total livestock density (LSU/ha of utilised agricultural area (UAA))
Farm management practices — manure management	Share of holdings with livestock which have manure storage facilities in total holdings with livestock Share of holdings with different manure storage facilities
Atmospheric emissions of ammonia	Ammonia emissions (kilotonnes per year)
Production of renewable energy	Share of primary energy production of renewable energy from agriculture and forestry to total energy production
GHG emissions	CO_2equivalents (kilotonnes per year)
Emissions of methane (CH_4) and nitrous oxide (N_2O)	
Area under agri-environment support	
Regional levels of good farming practice	
Regional levels of environmental targets	

3.2. Mitigation of GHG emissions in agriculture

Mitigation of GHGs emissions related to agriculture consist of three broad categories, depending on the underlying mechanism:

- Decrease in emissions;
- Avoiding (or displacing) emissions [12, 13].

GHG emissions from agriculture are associated with certain concerns therefore the evaluation of GHG mitigation measurements can be challenging [13]. This makes consensus difficult to analyse performance of EU MS in intensity of emissions.

Table 2. Mitigation measures [14].

Field	Mitigation effect
Crops and farming system management	Reduction of emissions Reduces direct nitrous oxide and indirect emissions
Fertilizer, manure and biomass management	Reduction of emissions
Soil management	Increases soil organic carbon, reduces emissions
Animal husbandry	Reduces methane emissions per kg meat Reduces emissions per kg output
Energy use	Reduces fossil emissions

3.3. GHG emissions mitigation measurements assessment indicators

The agricultural sector in respect to GHG emissions will become more and more important in the future [15, 16]. Therefore, the EU MS will need to establish a clear path towards climate friendly, sustainable agriculture which includes production of agricultural products with a high added value as well as development of bioenergy. Reduction of GHG emissions is one sustainability aspect; other aspects must also be taken into account when establishing reduction of GHG emissions in agricultural sector. Therefore, the monitoring, reporting and verification (MRV) of GHG emissions from agriculture sector is an important issue. Proposed indicators for determining the level of GHG emissions mitigation may be adopted in agricultural sector. However, the adoption of these indicators depends heavily on definite characteristics, since setting limit conditions might improve the MRV system in general, but can be confusing in multifunctional farms. Indicators for the assessment of soil carbon level, closed nutrient cycles, consumption and waste patterns, nitrous oxide dynamics, assessment of multi-functional farming systems, energy use and production of renewable energy were developed for the evaluation of the GHG emissions mitigation measurements. Chosen indicators were settled by reviewing literature and based on the opinion of experts in this area. Six major indicator groups, consisting of a combination of 11 agri-environmental indicators were used to evaluate the climate friendly agriculture and bioenergy development options (see Table 3).

Table 3. GHG emissions mitigation measurement indicator.

GHG emissions mitigation measurement indicator	**Analysed changes in values**	**Agri-environmental indicator**
Changes in soil carbon	Increase in soil carbon	Mineral fertilizer consumption
Closed nutrient cycles	Realise closed nutrient cycles in agriculture	Farm management practices — manure management
		Atmospheric emissions of ammonia from agriculture
Consumption and waste patterns	Change consumption and waste patterns	Cropping/livestock patterns
Nitrous oxide dynamics	Reduction of N_2O emissions	Emissions of CH_4 and N_2O GHG emissions
Multi-functional farming systems	Development of multi-functional farming systems	Area under agri-environment support
		Regional levels of good farming practice Regional levels of environmental targets
Energy use and production	Increase production of renewable energy	Production of renewable energy
	Decrease energy used at farm level	Energy use

Eleven criteria from six impact categories were chosen for the assessment of GHG emission mitigation. Criteria weights were determined by experts. Normalized and weighted values of indicators for the evaluation of GHG emissions mitigation for agricultural sector are shown in Fig. 2.

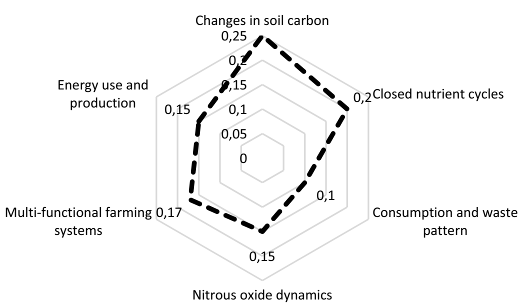

Fig. 2. Decision-making matrix.

4. Discussions and conclusions

The main objective of this study was to propose a tool with a set of indicators for assessment of GHG emissions mitigation measurements for agricultural sector. For this purpose, a modelling framework was built for the assessment of GHG emissions mitigation measurements based on application of agri-environmental indicators. The goal of the proposed set of indicators is mostly meant for decision-makers to estimate agriculture development options and to evaluate the sustainability of agricultural proposals and production of agricultural products with high added value. A set of comprehensive indicators should also be assessed in order to estimate the actual impact on the outcomes in relation to the first set of indicators selected.

The research gives insight on how to achieve climate friendly agriculture. The proposed indicators can be used to evaluate GHG emissions mitigation measurements in agriculture.

Acknowledgements

The work has been supported by the National Research Program “Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)”.

References

[1] Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O’Mara F, Rice C, Scholes B, Sirotenko O. Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; 2007. Available: http://www.ipcc.ch/publications_and_data/ar4/wg3/en/contents.html

[2] Smith P, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig EA, Haberl H, Harper R, House J, Jafari M, Masera O, Mbow C, Ravindranath NH, Rice CW, Robledo Abad C, Romanovskaya A, Sperling F, Tubiello F. Agriculture, Forestry and Other Land Use; 2014. Available: https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter11.pdf

[3] European Environmental Agency. Annual European Union greenhouse gas inventory 1990–2014 and inventory report; 2016. Available: http://www.eea.europa.eu/publications/annual-european-union-greenhouse-gas/

[4] European Environmental Agency. National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism; 2015. Available: http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2015

[5] European Commission. Economic Assessment of GHG mitigation policy options for EU agriculture; 2016. Available: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/economic-assessment-ghg-mitigation-policy-options-eu-agriculture-ecampa-2

[6] European Commission. Agricultural GHG emissions in the EU: an exploratory economic assessment of mitigation policy options; 2012. Available: http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=5079

[7] Bockstaller C, Guichard L, Makowski D, Aveline A, Girardin P, Plantureux S. Agri-environmental indicators to assess cropping and farming systems. A review. Agron. Sustain. Dev. 2008;28:139–149.

[8] Dace E, Blumberga D. How do 28 European Union Member States perform in agricultural greenhouse gas emissions? It depends on what we look at: Application of the multi-criteria analysis. Ecological Indicators 2016;71:352–358.

[9] Dace E, Muizniece I, Kaczala F. Searching for solutions to mitigate greenhouse gas emissions by agricultural policy decisions — Application of system dynamics modelingfor the case of Latvia. Science of the Total Environment, 2015;527–528:80–90.

[10] European Commission. Development of agri-environmental indicators for monitoring the integration of environmental concerns into the common agricultural policy; 2006. Available: http://www.eea.europa.eu/policy-documents/development-of-agri-environmental-indicators

[11] European Environmental Agency. Agriculture and environment in EU – 15 – the IRENA indication report; 2005. Available: http://www.eea.europa.eu/publications/eea_report_2005_6

[12] Smith P, Powlson DS, Smith JU, Falloon P, Coleman K. Meeting Europe’s climate change commitments: quantitative estimates of the potential for carbon mitigation by agriculture. Global Change Biology 2000;6:525–539.

[13] Smith P, Martino D, Cai Z, Gwary D, Janzen HH, Kumar P, McCarl BA, Ogle SM, O’Mara F, Rice C, Scholes RJ, Sirotenko O, Howden M, McAllister T, Pan G, Romanenkov V, Schneider UA, Towprayoon S. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. Agriculture, Ecosystems and Environment 2007:118:6–28.

[14] Gattinger A, Jawtusch J, Muller A. Mitigating Greenhouse Gases in Agriculture A challenge and opportunity for agricultural policies; 2011. Available: http://infoagro.net/programas/ambiente/pages/mitigacion/documentos/5.pdf

[15] Barisa A, Rosa M, Laicane I, Sarmins R. Application of Low-Carbon Technologies for Cutting Household GHG Emissions. Energy Procedia 2015;72,230–237.

[16] Bariss U, Avenitis E, Junghans G, Blumberga D. CO2 Emission Trading Effect on Baltic Electricity Market. Energy Procedia 2016;95:58–65.

CARBON BALANCE OF BIOGAS PRODUCTION FROM MAIZE IN LATVIAN CONDITIONS

Agronomy Research **19**(S1), 687–697, 2021
https://doi.org/10.15159/AR.21.085

Carbon balance of biogas production from maize in Latvian conditions

K. Bumbiere, A. Gancone, J. Pubule* and D. Blumberga

Riga Technical University, Institute of Energy Systems and Environment, Faculty of Electrical and Environmental Engineering, Azenes 12-K1, LV-1048 Riga, Latvia
*Correspondence: jelena.pubule@rtu.lv

Received: January 31st, 2021; Accepted: March 28th, 2021; Published: May 19th, 2021

Abstract. Production of biogas using bioresources of agricultural origin plays an important role in Europe's energy transition to sustainability. However, many substrates have been denounced in the last years as a result of differences of opinion on its impact on the environment, while finding new resources for renewable energy is a global issue. The aim of the study is to use a carbon balance method to evaluate the real impact on the atmosphere by carrying out a carbon balance to objectively quantify naturally or anthropogenically added or removed carbon dioxide from the atmosphere. This study uses Latvian data to determine the environmental impact of biogas production depending on the choice of substrate, in this case from specially grown maize silage. GHG emissions from specially grown maize use and cultivation (including the use of diesel fuel, crop residue and nitrogen fertilizer incorporation, photosynthesis), biogas production leaks, as well as digestate emissions (including digestate emissions and also saved nitrogen emissions by the use of digestate) are taken into account when compiling the carbon balance of maize. The results showed that biogas production from specially grown maize can save 1.86 kgCO_2eq emissions per 1 m^3 of produced biogas.

Key words: agriculture, bioenergy, biofuels, multicriteria analysis, sustainability.

INTRODUCTION

The European Union is the most progressive global leader on the path to climate change mitigation, therefore The European Commission presented the vision for climate-neutral economy by 2050 to keep global temperature increase below 2 °C above the pre-industrial level (Bereiter et al., 2015), with decarbonising the energy sector as one of the key points (European Council, 2019). Production of biogas using bioresources of agricultural origin plays an important role in Europe's energy transition to sustainability (European Council, 2014; European Council, 2019) due to the possibilities to use it for different purposes - transportation fuel, heat and electricity generation (Meyer et al., 2018).

The biogas production process integrates production (Chen et al., 2015), processing and recycling of degradable by-products (Li et al., 2019). Not only does the biogas produced by anaerobic digestion prevent greenhouse gas emissions and produce renewable energy, but also provides for the production of processed fertilizers, improving nutrient self-sufficiency in the agricultural sector (Timonen et al., 2019). The productivity of a biogas plant depends on different aspects, like the type of biomass (Melvere et al., 2017; Krištof & Gaduš, 2018; Bumbiere et al., 2020), digestion (Meiramkulova et al., 2018; Mano Esteves et al., 2019), availability of biomass, impurities that may harm microorganisms (Mehryar et al., 2017; Muizniece et al., 2019) and lignin content (Lauka et al., 2019).

The most important element of the biogas production system, is the choice of a substrate, because by knowing the composition of biomass, it is possible to predict the yield of biogas and its ratio of methane (Ugwu et al., 2020). Almost any organic material can be used for the biogas production, for example, paper, grass, animal waste, domestic or manufacturing sewage, food waste, agricultural products (Ugwu et al., 2020), but whereas finding new sources of renewable energy production is a global issue (Sauthoff et al., 2016; Siddique & Wahid, 2018) at the same time specially grown substrates are being rejected for the production of biogas (Schulz et al., 2018).

One of the substrates being rejected is the use of maize as a result of differences of opinion on its impact on the environment (Schulz et al., 2018), even though maize biogas yields and characteristics are far superior to other crops for biogas production (Pimentel, 2003; Gowik & Westhoff, 2011). Not only does maize have a high carbon fixation and assimilation capacity (Crafts-Brandner & Salvucci, 2002), but it can also be grown worldwide due to its high photosynthesis and resource utilization (Arodudu et al., 2017), even in conditions of drought, high temperatures and lack of various nutrients (Patzek, 2004). In addition, in the process of anaerobic digestion it is very important to use co-digestion, which allows to increase the productivity of produced biogas from 25 to 400% over mono-digestion (Cavinato et al., 2010; Shah et al., 2015). Co-digestion is often used for the very reason that the optimal carbon-nitrogen ratio on biogas production is in the rage of 20:1 to 30:1, but in general, manure has very low carbon ratio and it is important to mix it with other substrates that are carbon-rich like maize to increase the biogas yield.

Therefore, in this case, a carbon balance was developed and carried out to objectively quantify naturally or anthropogenically added or removed carbon dioxide from the atmosphere in order to determine the environmental impact of biogas production from specially grown substrates, in this case - maize silage.

Although many authors have acknowledged that, when analyzing biomass life cycle analysis, the range of results is quite wide (Murphy et al., 2014) due to the differences in various factors and system boundaries (Muench & Guenther, 2013), it is considered to be the best method for calculating Greenhouse gas (GHG) balance (Cherubini, 2010).

In this study carbon balance was carried out to determine the environmental impact in terms of greenhouse gas emissions by biogas production from specially grown maize.

The methodology was based on life cycle analysis, which included calculations of: emissions from maize silage cultivation due to tillage, mineral nitrogen fertilizers and fuel use in heavy machinery (both in the process of growing maize, in the process of preparing the substrate for biogas production, and in the process of incorporating digestate into the soil); emissions collected due to the photosynthesis process; emission leaks from biogas production process; emissions from the use of maize digestate fertilizer; emissions saved from the mineral fertilizer replacement with digestate.

Although the carbon balance method has been used so far, for example, to model the change of land use (Guo et al., 2017) or of forestry under various effects of forestry (Zubizarreta-Gerendiain et al., 2006), but there are no studies that have developed carbon balances to determine the environmental impact of substrate selection in biogas production.

METHODOLOGY

In order to calculate fuel emissions, data from an agricultural farm in Latvia was collected. It is important to note that the results of the calculations may differ, if a more detailed calculation is made, considering factors such as soil consistency and the technologies used, the efficiency of tractors and other indicators. The more efficient the techniques and methods used, the lower the emissions from maize production process. First, the number of times specific tractor-tillage techniques that use diesel fuel and the tons of diesel fuel consumed per 1 ha of the particular activity by off-road vehicles and other machinery were collected to an indicator of how many tons of diesel needed per hectare and how many tons of diesel fuel are consumed per year to process 1 ha of biogas maize fields. In turn, knowing the area of land that was used to grow the biogas maize substrate in a given year, can provide an indicator of all year's fuel consumption for biogas maize cultivation per ha (Table 1). Data from company producing biogas from maize in was used.

Table 1. Diesel fuel consumption for the production of maize for biogas production

	Times	Fuel needed, t ha^{-1} at a time	Fuel needed, t ha^{-1}	Area, ha	Fuel consumed over the area, t yr^{-1}
Plowing	1	0.025	0.025	5,382	134.335
Shuffle	1	0.008	0.008	5,382	44.778
Cultivation	1	0.007	0.007	5,382	40.300
Sowing	1	0.007	0.007	5,382	35.823
Plant protection + microelements	3	0.006	0.017	5,382	94.034
Shredding	1	0.029	0.029	5,382	156.724
Fertilizer application	3	0.004	0.012	5,382	67.167
Transportation field-farm	1	0.016	0.016	5,382	85.437
Compression	1	0.031	0.031	5,382	167.918
Picking from the pit, pouring, dumping	1	0.017	0.017	5,382	89.556
Incorporation of digestate into soil	1	0.015	0.015	5,382	80.601
In total	-	-	0.185	5,382	996.674

By finding out the lowest combustion heat of diesel fuel, it is possible to obtain consumed energy for field treatment (Intergovernmental Panel on Climate Change, 2006). But, knowing the energy consumed in the process in field cultivation as well as using the emission factors of the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines, it is possible to obtain the result in terms of tons of emissions from the use of fuel (Central Statistic Bureau, 2018). By determining the annual emissions, indicators - emissions from the processing of 1 ha of maize used for biogas production - are calculated.

During the special cultivation of maize, fuel is not the only source of emissions, it is also caused by the incorporation of crop residues into the soil, as well as the use of nitrogen, therefore the Tier 1 methodology from the 2006 IPCC guidelines was used to calculate nitrous oxide emissions from managed soils (IPCC, 2006). For direct nitrous oxide emissions from agricultural soils, the following equation was used.

$$N_2O - N = [(F_{SN} + F_{CR}) \cdot EF], \tag{1}$$

where $N_2O - N$ – N_2O emissions in units of nitrogen (direct N_2O emissions from treated soils, kg N_2O–N yr^{-1});
F_{SN} – the amount of nitrogen in the fertilizer applied to the soil kg N yr^{-1}; F_{CR} – N amount of maize residues entering the soil on an annual basis (above and below ground); EF – N_2O emission factor from N input, kg N_2O–N kg^{-1} N (input = 0.01).
The following equation was used to report kg N_2O–N emissions to N_2O emissions:

$$N_2O = N_2O - N \cdot 44/28 \tag{2}$$

One of the calculation parameters for estimating the direct nitrogen oxide emissions from the use of N in managed soils is the amount of pure nitrogen fertilizers per year. Data on the required inorganic fertilizers used in soils are taken from A. Kārkliņš book 'Calculation methods and standards for the use of soil treatment and fertilizers', which states that a maize yield of 31.8 t ha^{-1} requires 0.1 t ha^{-1} N fertilizer (IPCC, 2006).
Yield N per year is calculated on the Tier 1 methodology of the 2006 IPCC Guidelines:

$$F_{CR} = \text{Yield} \cdot \text{DRY x } Frac_{Renew} \cdot \text{Area x } R_{AG} \cdot N_{AG} \cdot \text{Area} \cdot R_{BG} \cdot N_{BG}, \tag{3}$$

where Yield – harvested maize yield (kg fresh maize yield ha^{-1}); DRY – dry matter part of harvested maize (kg dry matter kg^{-1} fresh matter); $Frac_{Renew}$ – total area of maize; Area – the total part of the area harvested for maize (ha $year^{-1}$); RAG – terrestrial, surface residue solids (AGDM) and maize harvest (Crop), kg dry matter (kg dry matter)$^{-1}$; N_{AG} – N surface plant residue content in maize (kg N kg^{-1} dry matter); R_{BG} – ratio of underground residues to maize yield (kg dry fraction kg^{-1} dry fraction); R_{BG} can be calculated by multiplying RBG-BIO by the total aboveground biomass to cereal yield ratio ($R_{BG} = [(AG_{DM} \cdot 1{,}000 + \text{Crop Crop})^{-1}]$; N_{BG} – the N content of underground residues of maize (kg N kg^{-1} dry matter) (0.007) (Liu et al., 2019).

To calculate the annual production of crop residues F_{CR}, the following calculation is required:

$$R_{AG} = \frac{\text{AGDM} \cdot 1{,}000}{\text{Crop}} \tag{4}$$

as well as an additional equation to estimate terrestrial surface solids AGDM (Mg ha^{-1}):

$$\text{AGDM} = \left(\frac{\text{Crop}}{1{,}000}\right) \cdot \text{slope} + \text{intercept}. \tag{5}$$

And the correction factor for estimating the dry matter yield is determined as:

$$\text{Crop} = \text{Yield Fresh} \cdot \text{DRY}, \tag{6}$$

where Crop – harvested dry yield fraction T, kg dry matter ha^{-1}; yield Fresh – part of fresh harvest T, kg fresh fraction ha^{-1}; DRY – dry matter fraction of harvested crop T, kg dry fraction (kg dry fraction)$^{-1}$ (IPCC, 2006).

Although the use of digestate in field fertilization reduces emissions compared to synthetic fertilizers, digestion of soil with digestate also generates greenhouse gas emissions (Ericsson et al., 2020). The results of analyzes obtained from the farm 'X' producing biogas from maize indicate that the N content of the digestate fertilizer is on average 3.8 kg t^{-1}. By knowing the N content of the digestate and the tons of digestate obtained, digestate fertilization emissions were calculated by the 2006 IPCC guidelines.

When looking at emissions from the biogas production process, it should be considered that although biogas is produced from maize, which is a renewable resource and recovers the carbon emissions that the plant has absorbed during its growth process, emissions from the biogas production process are taken into account. Based on the scientific article emission leakages account for 1% of biogas losses in biogas production, which includes both the 52% methane in it and the remaining 48%, which is assumed to be carbon dioxide (Blumberga et al., 2010).

Although GHG emissions result from field cultivation during maize cultivation, maize growth involves photosynthetic processes that sequester CO_2 from the atmosphere. In order to calculate the amount of CO_2 captured in a year in a certain area of biogas maize, the amount of dry matter is multiplied by the CO_2 sequestration factor (Scarlat et al., 2018).

RESULTS AND DISCUSSIONS

For the analysis of cultivation of maize and GHG emissions related with it, data about amount of total cultivated maize from 2017 were used. It can be seen that in 2017, GHG emissions are generated for the cultivation of maize, which was used as a substrate for biogas production, in total 3.53 kt CO_2eq yr^{-1} to treat it with heavy agricultural machinery, which uses diesel fuel. Knowing that 5,382 ha of biogas maize were managed in 2017, a result is obtained which shows that 0.66 tCO_2eq ha^{-1} per year of GHG emissions are generated in the management of biogas maize fields with agricultural machinery. Table 2 show fuel emission indicators per 1 ha of cultivated maize area used in calculations.

Table 2. Fuel emission indicators per 1 ha of cultivated maize area (based on IPCC, 2006)

	CO_2 emissions, t ha^{-1}	CH_4 emissions, kg ha^{-1}	N_2O emissions, kg ha^{-1}
Plowing	0.079	0.004	0.030
Shuffle	0.026	0.001	0.010
Cultivation	0.024	0.001	0.009
Sowing	0.021	0.001	0.008
Plant protection + microelements	0.055	0.003	0.021
Shredding	0.092	0.005	0.035
Fertilizer application	0.040	0.002	0.015
Transportation field-farm	0.050	0.003	0.019
Compression	0.099	0.006	0.038
Picking from the pit, pouring, dumping	0.053	0.003	0.020
Incorporation of digestate into soil	0.048	0.003	0.018
In total	0.588	0.033	0.225

In order to objectively determine the total greenhouse gas emissions from fuel use, it is necessary to convert them into a single unit of measurement - CO_2 equivalents. As the global warming potential (GWP) of 1 ton of CH_4 equals 25 tons of C_2 and 1 ton to N_2O equals 298 tons of CO_2, these values are used to produce total greenhouse gas emissions (IPCC, 2006). Table 3 shows CO_2eq emission indicators per 1 ha of biogas produced from specially cultivated maize.

Table 3. Fuel CO_2eq emission indicators per 1 ha of biogas produced from specially cultivated maize (based on IPCC, 2006)

	CO_2 emissions, $kgCO_2eq\ ha^{-1}$	CH_4 emissions, $kgCO_2\ eq\ ha^{-1}$	N_2O emissions, $kgCO_2\ eq\ ha^{-1}$	Total emissions, $tCO_2\ eq\ ha^{-1}$
Plowing	79.28	0.11	9.04	0.09
Shuffle	26.43	0.04	3.01	0.03
Cultivation	23.78	0.03	2.71	0.03
Sowing	21.14	0.03	2.41	0.02
Plant protection + microelements	55.49	0.08	6.33	0.06
Shredding	92.49	0.13	10.55	0.10
Fertilizer application	39.64	0.06	4.52	0.04
Transportation field-farm	50.42	0.07	5.75	0.06
Compression	99.09	0.14	11.30	0.11
Picking from the pit, pouring, dumping	52.85	0.07	6.03	0.06
Incorporation of digestate into soil	47.57	0.07	5.42	0.05
In total	588.16	0.82	67.06	0.66

The obtained data show that the highest emissions per ha occur per year due to harvesting and shredding to prepare maize for placing in the bioreactor, as well as due to compaction. The lowest emissions occur during sowing. Total indicative emissions from biogas production from specially grown maize per ha shown in Table 4.

Table 4. Total indicative emissions from biogas production from specially grown maize per ha (based on IPCC, 2006)

Indicative emissions	$tCO_2eq\ ha^{-1}$
Fuel emissions	0.656
Crop residue emissions	0.443
N fertilizer emissions	0.468
In total	1.567

As a result, it can be seen that the highest emissions per ha are caused by the use of fuel to perform all the necessary treatment operations with heavy machinery, which is almost 0.66 $tCO_2eq\ ha^{-1}$. Emissions from tillage with nitrogen fertilizers and crop residue incorporation in soil after harvest are relatively similar, amounting to 0.468 tCO_2 eq ha^{-1} and 0.443 tCO_2 eq ha^{-1}. In total indicative emissions from biogas production from specially grown maize creates 1.567 t CO_2 eq ha^{-1}.

The biogas production process produces a very valuable by-product – digestate. It contains significant amounts of nutrients that are suitable for enriching the soil (Brown et al., 2010; Pereira et al., 2018). The dry weight of digestate from biogas production using only maize is approximately 58.22% (Tambone et al., 2019). Digestion of fields with digestate can indirectly reduce greenhouse gas emissions, for example, digestate from 1 ha of maize green matter with a yield of 30 t ha^{-1} fully provides the required amount of potassium fertilizer and saves 31% phosphorus and 44–45% nitrogen fertilizer (Naglis-Liepa et al., 2014; Slepetiene et al., 2020).

Accordingly, using a maize yield of 31.8 t ha^{-1}, it is possible to provide fertilizer for 1.06 ha of maize. As a total of 25,700 ha of maize was grown in Latvia in 2017, the use of digestate is topical, as well as interviews with farmers conducted within the framework of this study revealed that unfortunately digestate for field fertilization is a shortage product, which is why additional synthetic fertilizers are used (Iocoli et al., 2019; Verdi et al., 2019).

Using digestate fertilizer in tillage, 1.19 ktCO_2eq emissions were saved in 2017, while indicative emissions show a reduction of 0.22 tCO_2eq ha^{-1}.

Although the use of digestate in field fertilization reduces emissions compared to synthetic fertilizers, digestion of soil with digestate also generates GHG emissions. The results of analyzes obtained from a farm producing biogas from maize indicate that the N content of the digestate fertilizer is on average 3.8 kg t^{-1}. Assuming that the maize harvest in 2017 is 171,147.6 tons and that the amount of digestate from the amount of mass fed to the bioreactor usually ranges from 90 to 95%, in 2017 158,311.53 tons of maize digestate were obtained, while knowing the N content of digestate per 1 ton, it is obtained that the total N per 5,382 ha of the whole maize area was 0.60 kt (Central Statistic Bureau, 2021). Based on the level 1 methodology of the 2006 IPCC guidelines, it is estimated that digestate fertilization caused 2.82 ktCO_2eq emissions in 2017 indicating on indicative emissions - 0.0005 tCO_2eq ha^{-1}.

The methane content of biogas produced exclusively from maize silage is known to be 52%, and the biogas yield per ton of maize is 202 cubic meters, which allows to calculate both the total amount of biogas produced from maize harvested in Latvia, which is 34,571,815.2 m^3 from 171,147.6 t maize (Latvia's National Inventory Report, 1990).

At a 1% biogas leak in its production process in 2017, 2.63 ktCO_2 eq GHG emissions were released into the atmosphere.

CONCLUSIONS

The research proves that carrying out carbon balance by the methodology based on life cycle analysis for assessment of the impact of biogas production from maize, it is possible to determine the environmental impact in terms of greenhouse gas emissions on the atmosphere. Despite the consumption of diesel fuel and emissions from the maize production process, maize absorbs much more carbon than is produced during photosynthesis, thus, if 1% of biogas leakage is assumed in its production process, as well as knowing by previous calculations that 34,571,815.2 m^3 of biogas can be obtained from 5,382 ha specially grown maize, its production from specially grown maize can save 1.86 kg CO_2 eq emissions per 1 m^3 of produced biogas (in normal conditions, pressure 760 mm Hg).

The carbon balance can be further improved by reducing emissions from the agricultural process by growing the substrate, for example, using zero-emission electric tractors for soil tillage, could reduce total biogas maize growing emissions by 43%. But there are also processes that would not be desirable to reduce emissions, for example, the tractor driving frequency reduction in the field - the fertilization process can theoretically be carried out immediately and at once, but fertilization is divided into several stages in order to gradually spread the substances for a favorable plant vegetation process, as well as not to promote pollution of water due to drainage that leads to erosion (Oshunsanya et al., 2019). After harvest, 28% of total emissions come from nitrogen emissions from crop residues (above and below ground). Unfortunately, these are emissions that cannot be reduced because, although these residues could theoretically be used for biogas production, the removal of crop residues from maize fields would have a negative impact on the environment and soil quality (Industrial Vehicle Technology International, 2021).

It is essential to combine efficiency in agriculture in order to reduce atmospheric emissions without losing sight of sustainable farming, so as not to have a negative impact on soil, water and the environment as a whole.

Results of this study demonstrates that using the carbon balance methodology developed in this work, it is possible to calculate the impact of biogas production and how the environment is affected as a result of substrate selection. Such calculations can be applied to any country or company in the world and it can be an excellent tool for political decision making, based not on discussion, but on quantitative calculations.

ACKNOWLEDGEMENTS. This research is funded by the Ministry of Economics of the Republic of Latvia, project 'Sustainable and renewable transport policy formulation in Latvia', project No. VPP-EM-2018/AER_2_0003.

REFERENCES

Arodudu, O.T., Helming, K., Voinov, A. & Wiggering, H. 2017. Integrating agronomic factors into energy efficiency assessment of agro-bioenergy production – A case study of ethanol and biogas production from maize feedstock. *Applied Energy* **198**, 426–439. https://doi.org/10.1016/j.apenergy.2017.02.017

Bereiter, B., Eggleston, S., Schmitt, J., Nehrbass-Ahles, C., Stocker, T.F., Fischer, H., Kipfstuhl, S. & Chappellaz, J. 2015. Revision of the EPICA Dome C CO2 record from 800 to 600-kyr before present. *Geophysical Research Letters* **42**, 542–549. https://doi.org/10.1002/2014GL061957

Blumberga, D., Dzene, I., Al Seadi, T., Rutz, D., Prassl, H., Kottner, M., Finsterwalder, T., Volk, S. & Janssen, R. 2010. *Biogas HANDBOOK*. https://docplayer.org/69439281-D-blumberga-i-dzene-t-al-sedi-d-rucs-h-prasls-m-ketners-t-finstervalders-s-folka-r-jansens-biogaze-rokasgramata.html. Accessed 05.01.2021

Brown, S., Beecher, N. & Carpenter, A. 2010. Calculator tool for determining greenhouse gas emissions for biosolids processing and end use. *Environmental Science & Technology* **44**, 9509–9515. https://doi.org/10.1021/es101210k

Bumbiere, K., Gancone, A., Pubule, J., Kirsanovs, V., Vasarevicius, S. & Blumberga, D. 2020. Ranking of Bioresources for Biogas Production. *Environmental and Climate Technologies* **24**(1), 368–377. https://doi.org/10.2478/rtuect-2020-0021

Cavinato, C., Fatone, F., Bolzonella, D. & Pavan, P. 2010. Thermophilic anaerobic co-digestion of cattle manure with agro-wastes and energy cr*ops: Comparison of pilot and full scale experiences.* Bioresource Technology **101**, 545–550. https://doi.org/10.1016/j.biortech.2009.08.043

Central Statistic Bureau, CSB database, (n.d.). https://www.csb.gov.lv/lv/statistika/db. Accessed 05.01.2021.

Central Statistic Bureau, Latvian energy balance in 2017. 2018. https://www.csb.gov.lv/lv/statistika/statistikas-temas/vide-energetika/energetika/meklet-tema/332-energobilance-2017-gada

Chen, X.Y., Vinh-Thang, H., Ramirez, A.A., Rodrigue, D. & Kaliaguine, S. 2015. Membrane gas separation technologies for biogas upgrading. *RSC Advances* **5**, 24399–24448. https://doi.org/10.1039/c5ra00666j

Cherubini, F. 2010. GHG balances of bioenergy systems - Overview of key steps in the production chain and methodological concerns. *Renewable Energy* **35**, 1565–1573. https://doi.org/10.1016/j.renene.2009.11.035

Crafts-Brandner, S.J. & Salvucci, M.E. 2002. Sensitivity of photosynthesis in a C4 plant, maize, to heat stress. *Plant Physiology* **129**, 1773–1780. https://doi.org/10.1104/pp.002170.

European Council | European Commission. 2014. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions. A policy framework for Climate and Energy in the period from 2020 to 2030. https://ec.europa.eu/clima/policies/strategies/2030_en. Accessed 04.01.2021.

European Council, European Commission. 2018. 2050 long-term strategy. Going climate-neutral by 2050. https://ec.europa.eu/clima/policies/strategies/2050_en. Accessed 04.01.2021.

European Council, A European Green Deal | European Commission. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en. Accessed 04.01.2021.

Ericsson, N., Nordberg, Å. & Berglund, M. 2020. Biogas plant management decision support - A temperature and time-dependent dynamic methane emission model for digestate storages. *Bioresource Technology Reports* **11**, 100454. https://doi.org/10.1016/j.biteb.2020.100454

Gowik, U.& Westhoff, P. 2011. The Path from C3 to C4 photosynthesis. *Plant Physiology* **155**, 56–63. https://doi.org/10.1104/pp.110.165308

Guo, R., Zhao, Y., Shi, Y., Li, F., Hu, J. & Yang, H. 2017. Low carbon development and local sustainability from a carbon balance perspective. *Resources, Conservation & Recycling* **122**, 270–279. https://doi.org/10.1016/j.resconrec.2017.02.019.

Industrial Vehicle Technology International, John Deere develops fully electric, autonomous tractor, (n.d.). https://www.ivtinternational.com/news/agriculture/john-deere-develops-fully-electric-autonomous-tractor.html. Accessed 05.01.2021.

Iocoli, G.A., Zabaloy, M.C., Pasdevicelli, G. & Gómez, M.A. 2019. Use of biogas digestates obtained by anaerobic digestion and co-digestion as fertilizers: Characterization, soil biological activity and growth dynamic of Lactuca sativa L. *Science of the Total Environment* **647**, 11–19. https://doi.org/10.1016/j.scitotenv.2018.07.444

IPCC - Task Force on National Greenhouse Gas Inventories. 2006. 2. https://www.ipcc-nggip.iges.or.jp/public/2006gl/ Accessed 05.01.2021.

Krištof, K. & Gaduš, J. 2018. Effect of alternative sources of input substrates on biogas production and its quality from anaerobic digestion by using wet fermentation. *Agronomy Research* **16**(3), 769–783. https://doi.org/10.15159/AR.18.146

Latvia's National Inventory Report. 1990. http://www.meteo.lv/. Accessed 05.01.2021.

Lauka, D., Slisane, D., Ievina, L., Muizniece, I. & Blumberga, D. 2019. When Bioeconomy Development Becomes a Biomass Energy Competitor. *Environmental and Climate Technologies* **23**, 347–359. https://doi.org/10.2478/rtuect-2019-0100

Li., Y., Wen, Z., Li, J., Cai, L. & Wang, H. 2019. Feasibility of utilizing by-product biogas in breweries after being decarbonized for refrigeration chiller and related primary energy efficiency analysis. Sustainable *Energy Technologies and Assessments* **31**, 390–400. https://doi.org/10.1016/j.seta.2019.01.001

Liu, Z., Gao, J., Gao, F., Liu, P., Zhao, B. & Zhang, J. 2019. Late harvest improves yield and nitrogen utilization efficiency of summer maize. *Field Crops Research* **232**, 88–94. https://doi.org/10.1016/j.fcr.2018.12.014

Mano Esteves, E.M., Naranjo Herrera, A.M., Pecanha Esteves, V.P. & Vaz Morgado, C.R. 2019. Life cycle assessment of manure biogas production: A review. *Journal of Cleaner Production* **219**, 411–423. https://doi.org/10.1016/j.jclepro.2019.02.091

Meiramkulova, K., Bayanov, A., Ivanova, T., Havrland, B., Kára, J. & Hanzlíková, I. 2018. Effect of different compositions on anaerobic co-digestion of cattle manure and agro-industrial by-products. *Agronomy Research* **16**(1), 176–187. https://doi.org/10.15159/AR.18.008

Melvere, M., Ivanovs, K., Pubule, J. & Blumberga, D. 2017. Use of round goby (Neogobius melanostomus) processing waste in bioeconomy. *Energy Procedia* **128**, 484–490. https://doi.org/10.1016/j.egypro.2017.09.064

Mehryar, E., Ding, W.M., Hemmat, A., Hassan, M., Bi, J.H., Huang, H.Y. & Kafashan, J. 2017. Anaerobic co-digestion of oil refinery wastewater and chicken manure to produce biogas, and kinetic parameters determination in batch reactors. *Agronomy Research* **15**(5), 1983–1996. https://doi.org/10.15159/AR.17.072.

Meyer, A.K.P., Ehimen, E.A. & Holm-Nielsen, J.B. 2018. Future European biogas: Animal manure, straw and grass potentials for a sustainable European biogas production. *Biomass and Bioenergy* **111**, 154–164. https://doi.org/10.1016/j.biombioe.2017.05.013

Muench, S. & Guenther, E. 2013. A systematic review of bioenergy life cycle assessments. *Applied Energy* **112**, 257–273. https://doi.org/10.1016/j.apenergy.2013.06.001.

Muizniece, I., Zihare, L., Pubule, J. & Blumberga, D. 2019. Circular Economy and Bioeconomy Interaction Development as Future for Rural Regions. Case Study of Aizkraukle Region in Latvia. *Environmental and Climate Technologies* **23**, 129–146. https://doi.org/10.2478/rtuect-2019-0084

Murphy, F., Devlin, G. & McDonnell, K. 2014. Forest biomass supply chains in Ireland: A life cycle assessment of GHG emissions and primary energy balances. *Applied Energy* **116**, 1–8. https://doi.org/10.1016/j.apenergy.2013.11.041

Naglis-Liepa, K. & Pelse, M. 2014. Biogas production from agricultural raw materials. https://llufb.llu.lv/conference/economic_science_rural/2014/ESRD_34_2014_Productions-172-179.pdf

Oshunsanya, S.O., Li, Y. & Yu, H. 2019. Vetiver grass hedgerows significantly reduce nitrogen and phosphorus losses from fertilized sloping lands. *Science of the Total Environment* **661**, 86–94. https://doi.org/10.1016/j.scitotenv.2019.01.129

Patzek, T.W. 2004. Thermodynamics of the corn-ethanol biofuel cycle, CRC. Critical Reviews in Plant Sciences **23**, 519–567. https://doi.org/10.1080/07352680490886905.

Pereira Domingues Martinho, V.J. 2018. Interrelationships between renewable energy and agricultural economics: An overview. *Energy Strategy Reviews* **22**, 396–409. https://doi.org/10.1016/j.esr.2018.11.002

Pimentel, D. 2003. Ethanol fuels: Energy balance, economics, and environmental impacts are negative. *Natural Resources Research* **12**, 127–134. https://doi.org/10.1023/A:1024214812527

Sauthoff, S., Musshoff, O., Danne, M. & Anastassiadis, F. 2016. Sugar beet as a biogas substrate? A discrete choice experiment for the design of substrate supply contracts for German farmers. *Biomass and Bioenergy* **90**, 163–172. https://doi.org/10.1016/j.biombioe.2016.04.005

Scarlat, N., Dallemand, J.F. & Fahl, F. 2018. Biogas: Developments and perspectives in Europe. *Renewable Energy* **129**, 457–472. https://doi.org/10.1016/j.renene.2018.03.006

Schulz, V.S., Munz, S., Stolzenburg, K., Hartung, J., Weisenburger, S., Mastel, K., Möller, K., Claupein, W. & Graeff-Hönninger, S. 2018. Biomass and biogas yield of maize (Zea mays l.) grown under artificial shading. *Agriculture* **8**. https://doi.org/10.3390/agriculture8110178

Shah, F.A., Mahmood, Q., Rashid, N., Pervez, A., Raja, I.A. & Shah, M.M. 2015. Co-digestion, pretreatment and digester design for enhanced methanogenesis. *Renewable & Sustainable Energy Reviews* **42**, 627–642. https://doi.org/10.1016/j.rser.2014.10.053

Siddique, M.N.I. & Wahid, Z.A. 2018. Achievements and perspectives of anaerobic co-digestion: A review. *Journal of Cleaner Production* **194**, 359–371. https://doi.org/10.1016/j.jclepro.2018.05.155

Slepetiene, A., Volungevicius, J., Jurgutis, L., Liaudanskiene, I., Amaleviciute-Volunge, K., Slepetys, J. & Ceseviciene, J. 2020. The potential of digestate as a biofertilizer in eroded soils of Lithuania. *Waste Management* **102**, 441–451. https://doi.org/10.1016/j.wasman.2019.11.008.

Tambone, F., Orzi, V., Zilio, M. & Adani, F. 2019. Measuring the organic amendment properties of the liquid fraction of digestate. https://doi.org/10.1016/j.wasman.2019.03.024

Timonen, K., Sinkko, T., Luostarinen, S., Tampio, E. & Joensuu, K. 2019. LCA of anaerobic digestion: Emission allocation for energy and digestate. *Journal of Cleaner Production* **235**, 1567–1579. https://doi.org/10.1016/j.jclepro.2019.06.085

Ugwu, S.N., Biscoff, R.K. & Enweremadu, C.C. 2020. A meta-analysis of iron-based additives on enhancements of biogas yields during anaerobic digestion of organic wastes. *Journal of Cleaner Production* **269**, 122449. https://doi.org/10.1016/j.jclepro.2020.122449

Verdi, L., Kuikman, P.J., Orlandini, S., Mancini, M., Napoli, M. & Dalla Marta, A. 2019. Does the use of digestate to replace mineral fertilizers have less emissions of N_2O and NH 3? *Agricultural and Forest Meteorology* **269–270**, 112–118. https://doi.org/10.1016/j.agrformet.2019.02.004

Zubizarreta-Gerendiain, A., Pukkala, T. & Peltola, H. 2016. Effects of wood harvesting and utilisation policies on the carbon balance of forestry under changing climate: A Finnish case study. *Forest Policy and Economics* **62**, 168–176. https://doi.org/10.1016/j.forpol.2015.08.007

RANKING OF BIORESOURCES FOR BIOGAS PRODUCTION

Environmental and Climate Technologies
2020, vol. 24, no. 1, pp. 368–377
https://doi.org/10.2478/rtuect-2020-0021
https://content.sciendo.com

Ranking of Bioresources for Biogas Production

Ketija BUMBIERE[1]*, Agita GANCONE[2], Jelena PUBULE[3], Vladimirs KIRSANOVS[4], Saulius VASAREVICIUS[5], Dagnija BLUMBERGA[6]

[1–4, 6]*Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV–1048, Latvia*

[5]*Faculty of Environmental Protection, Vilnius Gediminas Technical University, Saulėtekio al. 11, Vilnius 10221, Lithuania*

Abstract **– Production of biogas using bioresources of agricultural origin plays an important role in Europe's energy transition to sustainability and to a climate-neutral economy. The usage of some substrates like maize has been increasingly denounced in the last years and there is currently an active discussion about future subsidies to biogas producers depending on the substrate used. The aim of this study is to compare and rank different substrates for biogas production considering their economic feasibility, substrate efficiency and environmental aspects. During the research, eight substrates were evaluated: cattle manure, pig manure, poultry manure, straw, wood, maize silage, waste, and sewage sludge. In order to reach the research goal, multi-criteria analysis using TOPSIS methodology was applied to objectively determine which of the substrates considered would be the most suitable for biogas production in Latvia. The results obtained showed that pig manure is the most suitable raw material for biogas production in Latvia, while poultry manure was ranked second, with little difference in value from pig manure.**

Keywords **– Biogas; economic feasibility; maize; manure; substrate efficiency; TOPSIS.**

1. INTRODUCTION

Production of biogas using bioresources of agricultural origin plays an important role in Europe's energy transition to sustainability and a climate-neutral economy [1]–[3]. The transition to clean energy has already proven its worth by modernizing the EU's economy, promoting sustainable economic growth and prosperity, as well as improving the environment, creating new jobs and delivering benefits for citizens [4]. Given that around 6 million tons of agricultural waste is produced in the world yearly and the emphasis on pathways and strategic priorities for transition to a net-zero GHG emission economy, there is a promising future for the development of biogas production, especially for upgraded biogas to biomethane, which is flexible both in use and storage and because its production from agricultural, industrial waste and sewage sludge protects soil, air and water from pollution [5], [6]. Not only does biogas produced by anaerobic digestion prevent greenhouse gas emissions and produce renewable energy from waste, but also provides for the production of processed fertilizers, improving nutrient self-sufficiency in the agricultural sector [7].

The biogas production process is an environmental technology that integrates production [8], processing and recycling of degradable by-products [9]. In 2014 there were 54 first- and second-generation biogas plants [10] operating in Latvia with a total capacity of 54.92 MW (3.1 PJ) and

* Corresponding author.
E-mail address: ketija.bumbiere@rtu.lv

out of those 54 biogas plants, 44 used agricultural waste, 7 used municipal waste in landfills, but only 3 used domestic or industrial sewage and residues from food production (industrial waste) [11]. Consumption of biogas produced in 2017 increased to 80.73 MW (3.9 PJ) since 2014, reaching a 25.81 % increase of biogas production [12].

The productivity of a biogas plant depends on different aspects, like type of biomass [13], digestion [14], availability of biomass, impurities that may harm microorganisms [15] and lignin content [16].

Different types of manure present variation in organic composition and dry matter content (1.5–30.0 %), which affects the biogas produced. Co-digestion is often used for the very reason that the optimal carbon-nitrogen ratio on biogas production is in the rage of 20:1 to 30:1, but in general, manure has very low carbon ratio and it is important to mix it with other substrates that are carbon-rich to increase the biogas yield [14], [17].

TABLE 1. YIELD OF VARIOUS RAW MATERIALS [18]

	Yield of methane, %	**Yield of biogas, m^3/t**
Cattle manure (liquid)	60	25
Cattle manure	60	45
Pig manure (liquid)	65	28
Pig manure	60	60
Poultry manure	60	80
Maize silage	52	202
Grass silage	52	172
Organic waste	61	100

The most commonly used substrate with manure for co-digestion is maize silage. The yield of different raw materials is shown in Table 1. Comparing the biogas yield of maize silage with the biogas yield of liquid cattle manure, the biogas yield from maize silage is 8,08 times higher [19].

The use of lignocellulosic substrates after pre-treatment [20] for biogas production should be evaluated. Given that the use of maize and rapeseed silage in biogas production will no longer be acceptable, it is necessary to find new raw materials that occurs as a result of other processes as waste. Considering that a half of Latvia's territory is covered by forests in 2016, and 36.5 % of Latvia's territory is covered by agricultural lands, Latvia has a big potential to use harvesting and agricultural crop residues and waste, which have high levels of lignin in their content [21].

Grasslands have a variety of functions in agriculture – not only are they primarily the main source of feed for livestock, but overall, they provide benefits such as carbon storage and soil protection from erosion, groundwater formation and habitat formation in diverse landscapes and natural foundations [22]. Although grasslands can be used in the production of lignocellulosic bioethanol, synthetic natural gas or synthetic biofuels, according to the Green Biorefineries concept, the sustainable use of grass biomass is directly linked to the production of biogas [22]. Knowing the feasibility of successful processing of such raw materials and their practical application, it is understandable that they are potential raw materials also in the agricultural conditions of Latvia.

Anaerobic digestion has been mainly implemented for the management of animal manure, organic and agricultural waste, sewage sludge, plant green mass etc. [23]. Theoretically it is possible to use forest and wood processing waste and peat [24].

Manure is the most suitable material for biogas production. The easiest way to get biogas is from cattle manure. The dry matter content of the manure depends on the used amount of litter, moreover if a lot of washing water is used, the manure is watery [25].

Pig manure is also very suitable for biogas production, because it contains not only manure, but also feed residue and litter. Bird manure is very suitable for biogas production also, but there tends to be sand and feathers mixed in the manure, which can cause problems, when specially adopted pumps are not used. Because of the high concentration of nitrogen, it is advisable to mix poultry manure with cattle manure [24].

2. METHODOLOGY

Multi-criteria analysis was carried out to determine Latvia's biogas sector potential – to predict the best feedstock depending on resources available in the country, which of the substrates for biogas production has the highest potential and sustainability. The following raw materials were analysed in this multi-criteria analysis: cattle manure, pig manure, poultry manure, sewage sludge, organic waste, wood, straw, maize silage.

The year 2017 was used for data collection, and multi-criteria analysis does not take into account the size of the farms, which is related to the actual number of livestock, manure collection technology and the transportation distance from the raw material extraction site to the biogas plant.

For the purpose of multicriteria analysis, the efficiency of different feedstocks in terms of yield, were how many cubic meters of biogas can be obtained from a ton of a given feedstock was analysed. The efficiency of raw materials was determined as an average value [26]–[28].

In order to determine the importance of using a particular substrate in the production of biogas, data was collected on how many emissions could be eliminated altogether, thus approximating the proportion of their availability and importance, and environmental impact depending on how much this material is produced in one year and its emission factor. To calculate objectively the amount of emissions that could potentially be avoided (both nitrous oxide and methane), emissions were compared to carbon dioxide equivalents and added up. 1 kg of nitrous oxide was calculated as 298 kg carbon dioxide, while 1 kg of methane was calculated as 25 kg carbon dioxide [28].

In total three main criteria were considered: substrate efficiency, environmental friendliness, and economic feasibility.

TABLE 2. CHARACTERISTICS OF LIVESTOCK NUMBERS AND EMISSIONS FROM MANURE MANAGEMENT IN 2017 [29]

	Mature dairy cattle	Other mature cattle	Growing cattle	Pig	Poultry
Population size, thousands	150.4	77.5	177.9	320.6	4943.8
CH_4 emissions, kt	2.60	0.15	0.20	0.79	0.07
CH_4 emissions, kt CO_2 equivalent	65.00	3.75	5.00	19.75	1.75
N_2O emissions, kt	0.11	0.01	0.02	0.02	0.01
N_2O emissions, kt CO_2 equivalent	32.78	2.98	5.96	5.96	2.98
Emissions in total, kt CO_2 equivalent	97.78	6.73	10.96	25.71	4.73

In order to determine, which is the most important criteria, a survey and a vote was carried out among different experts in the field of biogas production. As a result, of the 100 % experts voted that the most important criteria was climate friendliness with 35 % as the deciding factor. Only 5 % less important was the technological aspect responsible for substrate efficiency. The economic justification for this sector's priorities and comparison with the other two criteria was determined as the last one with 35 %.

In order to objectively determine the potential of manure for biogas production, a summary was made, which is shown in Table 2, to summarize the amount of specific livestock manure and emissions in Latvia in one year.

Since the information about livestock population and emissions for 2017 is available, it is used for the analysis. Table 2 shows that although poultry has the highest numbers, methane emissions from cattle are the highest and to use them for biogas production would be more significant, if only by looking at annual emissions, because altogether cattle emissions reach 115.47 kt/year, but pig manure is also a very important resource, although the number of pigs is 21 % lower, the emissions emitted are still significant.

Domestic and industrial wastewater emissions are calculated and showed in Table 3.

TABLE 3. WASTEWATER DRY CONTENT AND EMISSIONS IN 2017 [29]

	Total organic product, kt DC/year	CH_4 emissions, kt	CH_4 emissions as CO_2 equivalent, kt	N_2O emissions, kt	N_2Oemissions as CO_2 equivalent, kt	In total, kt CO_2 equivalent
Domestic wastewater	42.71	3.16	79.00	0.11	32.78	111.78
Industrial wastewater	13.51	0.07	1.75	0.00	0.00	1.75

Methane emissions from solid waste are shown in Table 4. In total both managed and unmanaged waste disposal sites emit 403.50 kt CO_2 equivalent per year, because of the organic waste in disposal sites. This problem could be partly overcome by changing the shopping and eating habits of people, thus reducing the amount of food thrown away. However, such a shift in people's behaviour takes a long time and, until it is successful, this "waste" can be used effectively in biogas production because it is creating the biggest emissions of all analysed raw materials in this research.

TABLE 4. ANNUAL SOLID WASTE EMISSIONS IN 2017 AT THE WASTE DISPOSAL SITES [29]

	Annual waste, kt	CH_4 emissions, kt	CH_4 emissions, kt CO_2 equivalent
Managed waste disposal sites	230.62	10.55	263.75
Unmanaged waste disposal sites	–	5.59	139.75

3. RESULTS

In order to determine, which feedstock is the most economically advantageous for biogas production, information on feedstock prices was collected. The largest advertisement portal in Latvia www.ss.com was used to find out the price of manure, as well as straw and corn, which showed that, on average, cattle manure is sold for 3 €/t , poultry manure for 2 €/t, but pig manure is charged a very symbolic price of about 1 €/t [30]. Straw bales were found to weigh an average of 0.45 t, but 1 bale is sold for an average of 7 €/piece, while 1 t of corn silage costs 50 € [30]. By making the calculations, 1 t of straw costs 15.56 €/t. A symbolic price of 1 €/t was adopted for wastewater sludge. The price of organic waste was determined by obtaining information on the website of the largest landfill site in Latvia, where it is offered to deliver the organic waste to landfill for 60.81 €/t +VAT. It means that the cost of transferring the waste in total with VAT costs is 73.58 €/t [31]. As the transfer of this waste costs a certain amount of money, its use at the on-farm biogas plant means a reduction in costs and for that reason the cost of organic waste is shown with a minus sign in Table 5. According to surveys of the biggest woodchip suppliers, its price is currently 12 €/m^3. Given that 1 t of woodchips is equivalent to 3.5 m^3 of woodchips, the price per t is assumed to be 42 €.

Summarizing the information obtained on the biogas efficiency of the particular feedstocks as well as the price per t of the feedstock, it is possible to obtain an economic justification for each substrate. To obtain the cost of producing 1 m^3 of biogas from a given substrate, the substrate price was divided by the substrate efficiency.

TABLE 5. CALCULATION OF ECONOMIC JUSTIFICATION FOR EACH SUBSTRATE

	Effectivity, yield of biogas, m^3/t	**Price of the feedstock, €/t**	**Economically justified, €/m^3 biogas**
Cattle manure	35	3.00	0.09
Pig manure	44	1.00	0.02
Poultry manure	80	2.00	0.03
Sewage sludge	218	1.00	0.01
Organic waste	100	–73.58	–0.74
Wood	35.5	42.00	1.18
Straw	190	15.56	0.08
Maize silage	202	45.00	0.25

As a result, the three main criteria identified as determinants of biogas substrate selection were summarized in Table 6 for objective comparison.

TABLE 6. MULTI-CRITERIA ANALYSIS VALUES

	Effective (yield of biogas, m^3/t)	**Environmentally friendly (emissions to be collected in Latvia, kt CO_2 eq/year)**	**Economically justified (€/m^3 biogas)**
Cattle manure	35.0	115.47	0.09
Pig manure	44.0	25.71	0.02
Poultry manure	80.0	4.73	0.03
Sewage sludge	218.0	113.53	0.01
Organic waste	100.0	403.50	–0.74
Wood	35.5	0.00	1.18
Straw	190.0	0.00	0.08
Maize silage	202.0	–6.56	0.25

After gathering information about the substrates, it can be seen that the highest efficiency of biogas production is in the production of biogas from sewage sludge as well as maize silage. Straw does not lag behind in the productivity of maize silage biogas. The lowest efficiency is observed in cattle manure and wood, with average efficiency values almost equal. Only slightly higher efficiency is observed in pig manure.

Considering which raw material should preferably be selected for the most environmentally friendly production of biogas, it appears that the most airborne emissions can be prevented by anaerobic fermentation of organic waste. The use of sewage sludge for biogas production as well as the use of cattle manure would provide about 3.4 times less, but still significant emission savings. Equally important is the use of pig manure, but their total methane emissions are lower due to pig numbers. It is also very important to use poultry manure, as their biogas efficiency is only 20 % lower than the efficiency of solid waste, but their environmental impact is less significant due to the quantitative value of this manure. The emissions from biogas maize production in Latvia is the only substrate considered here that generates emissions rather than being neutral.

Economically, the most detrimental raw material for biogas production is wood, if purchased as wood chips, but the most advantageous is the use of organic waste, as it not only allows biogas to be produced, but also helps to reduce the cost of waste transfer to landfills.

In order to determine objectively the best raw material for biogas production, the TOPSIS model was developed.

After the TOPSIS methodology calculations were made, a rating was obtained of which, according to the accepted three criteria (environment, technology, economic), indicates where the given substrate is ranked from the most suitable substrate for biogas production in Latvia ranked first to the worst substrate from this list, ranked in the last 8th place.

Pig and poultry manure were ranked in the first two places according to the criteria, while straw with pre-treatment was ranked 3rd; cattle manure was ranked 4th, and sewage sludge ranked 5th. The last three places are organic waste, corn and wood, which took a convincing last place in the ranking.

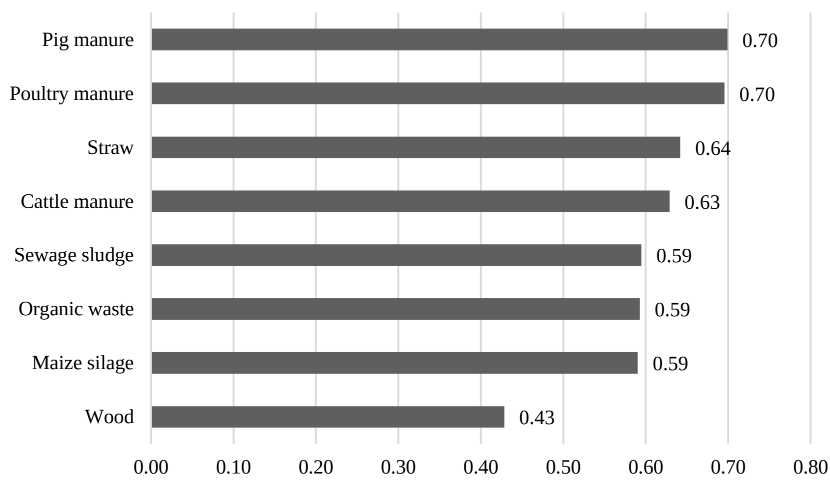

Fig. 1. Relative closeness to the ideal solution with TOPSIS method.

Fig. 1 shows that the raw materials are basically divided into four groups according to the suitability of the substrate for biogas production:

- Group with convincing highest relative closeness to the ideal solution with TOPSIS method, which includes pig and poultry manure and have very similar values;
- Group with the second highest relative closeness to the ideal solution with TOPSIS

method, which includes straw and cattle manure and have very small difference in values between them;
- Group which includes sewage sludge, organic waste and maize silage – feedstocks, the numerical value of which in terms of relative closeness to the ideal solution is nearly the same;
- Group which consists with the worst feedstock among the ones considered for the particular biogas production method is wood.

4. Conclusions

A multi-criteria analysis using TOPSIS methodology and taking into account three main parameters: economic feasibility, substrate efficiency, and environmental aspects, showed that pig manure is the most suitable raw material for biogas production in Latvia, while poultry manure was ranked second, with very little difference in value from pig manure.

Despite the claim that lignocellulose rich plants are not a successful choice for biogas production, straw was the third best substrate for biogas production in Latvia, and cattle manure was in 4th place. Wood was identified as the most unsuccessful choice for biogas feedstock.

The penultimate place in the ranking was for specially grown maize for biogas production, which until now has been a popular substrate for agricultural biogas production.

Based on the criteria used in the model, the organic waste and sewage sludge are roughly the same as biogas maize in the rating. This work proves that pre-treatment straw can serve as a great substitute for biogas maize.

The use of any waste for energy production is important, but the greatest potential shows in agricultural biogas from manure and straw.

Acknowledgement

The research is funded by the Ministry of Economics of the Republic of Latvia, project "Sustainable and renewable transport policy formulation in Latvia (4muLATe)", project No. VPP-EM-2018/AER-2-0003.

References

[1] European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions. A policy framework for Climate and Energy in the period from 2020 to 2030, 2014. [Online]. [Accessed 15.05.2015]. Available: https://ec.europa.eu/clima/policies/strategies/2030_en.

[2] European Commission. 2050 long-term strategy. Going climate-neutral by 2050, 2018. [Online]. [Accessed 15.05.2015]. https://ec.europa.eu/clima/policies/strategies/2050_en

[3] Bereiter B., Eggleston S., Schmitt J., Nehrbass-Ahles C., Stocker T. F., Fischer H., Kipfstuhl S., Chappellaz J. Revision of the EPICA Dome C CO_2 record from 800 to 600 kyr before present. *Geophysical Research Letters* 2015:42(2):542–549. https://doi.org/10.1002/2014GL061957

[4] European Commission. Communication from the Commission to the European parliament, the European council, the council, the European economic and social committee, the committee of the regions and the European investment bank. A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, 2018. [Online]. [Accessed 15.05.2015] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773.

[5] Scarlat N., Dallemand J. F., Fahl F. Biogas: Developments and perspectives in Europe. *Renewable Energy* 2018:129 (A):457–472. https://doi.org/10.1016/j.renene.2018.03.006

[6] Yu Q., Liu R., Li K., Ma R. A review of crop straw pretreatment methods for biogas production by anaerobic digestion in China. *Renewable and Sustainable Energy Reviews* 2019:107:51–58. https://doi.org/10.1016/j.rser.2019.02.020

[7] Timonen K., Sinkko T., Luostarinen S., Tampio E., Joensuu K. LCA of anaerobic digestion: Emission allocation for energy and digestate. *Journal of Cleaner Production* 2019:235:1567–1579. https://doi.org/10.1016/j.jclepro.2019.06.085

[8] Chen X. Y., Vinh-Thang H., Ramirez A. A., Rodrigue D., Kaliaguine S.. Membrane gas separation technologies for biogas upgrading. *RSC Advances* 2015:5:31:24399–24448. https://doi.org/10.1039/C5RA00666J

[9] Karklins A. Biogas production in Latvia. Possibilities of obaining and using biomethane [Online]. [Accessed 15.05.2015]. http://www.sam.gov.lv/images/modules/items/PDF/item_6133_6_LBA_biometans_SM_06.2016.pdf.

[10] BiogasAction – New developments in Latvia. [Online]. [Accessed 15.05.2015]. https://www.fedarene.org/biogasaction-new-developments-latvia-23060.

[11] Development of biogas in Latvia [Online]. [Accessed 15.05.2015]. http://latvijasbiogaze.lv/index.php?c=3.

[12] Central Statistical Bureau of Latvia. Renewable energy consumption in 2017 [Online]. [Accessed 15.05.2015]. https://www.csb.gov.lv/lv/statistika/statistikas-temas/vide-energetika/energetika/meklet-tema/2407-atjaunigo-energoresursu-paterins-2017-gada.

[13] Meyer A. K. P., Ehimen E. A., Holm-Nielsen J. B. Future European biogas: Animal manure, straw and grass potentials for a sustainable European biogas production. *Biomass and Bioenergy* 2018:111:154–164. https://doi.org/10.1016/j.biombioe.2017.05.013

[14] Mano Esteves E. M., Naranjo Herrera A. M., Peçanha Esteves V. P., Morgado C. R. V. Life cycle assessment of manure biogas production: A review. *Journal of Cleaner Production* 219:411–423. https://doi.org/10.1016/j.jclepro.2019.02.091

[15] Muizniece I., Zihare L., Pubule J., Blumberga D. Circular Economy and Bioeconomy Interaction Development as Future for Rural Regions. Case Study of Aizkraukle Region in Latvia. *Environmental and Climate Technologies* 2019:23(3):129–146. https://doi.org/10.2478/rtuect-2019-0084

[16] Lauka D., Slisane D., Ievina L., Muizniece I., Blumberga D. When Bioeconomy Development Becomes a Biomass Energy Competitor. *Environmental and Climate Technologies* 2019:23(3):347–359. https://doi.org/10.2478/rtuect-2019-0100.

[17] Conti F., Saidi A., Goldbrunner M., CFD Modelling of Biomass Mixing in Anaerobic Digesters of Biogas Plants. *Environmental and Climate Technologies* 2019:23(3):57–69. https://doi.org/10.2478/rtuect-2019-0079

[18] Blumberga, D., Veidenbergs, I., Romagnoli, F., Rochas, C., Žandeckis, A. *Bioenergy Technologies*, Riga: RTU, 2011.

[19] European Environmental Agency. EMEP/EEA air pollutant emission inventory guidebook 2019. Biological treatment of waste – anaerobic digestion at biogas facilities [Online]. [Accessed 15.05.2015]. Available: file:///C:/Users/jelen/Downloads/5.B.2%20Biological%20treatment%20of%20waste%20-%20anaerobic%20Digestion%20Biogas%202019.pdf.

[20] Li K., Liu R., Sun C. A review of methane production from agricultural residues in China. *Renewable and Sustainable Energy Reviews* 2016:54:857–865. https://doi.org/10.1016/j.rser.2015.10.103

[21] Ministry of Environment and Regional development of Latvia. Land policy plan for 2016–2020. [Online]. [Accessed 15.05.2015]. (in Latvian) http://www.varam.gov.lv/in_site/tools/download.php?file=files/text/Sab_lidzdaliba/sab_apsp/VARAM_Zemes_politikas_plans_211116.pdf

[22] Prochnow A., Heiermann M., Plöchl M., Linke B., Idler C., Amon T., Hobbs P. J. Bioenergy from permanent grassland – A review: 1. Biogas. *Bioresource Technology* 2009:100:21:4931–4944. https://doi.org/10.1016/j.biortech.2009.05.070

[23] Chiumenti A., Borso F., Limina S. Dry anaerobic digestion of cow manure and agricultural products in a full-scale plant: Efficiency and comparison with wet fermentation. *Waste Management* 2018:71:704–710. https://doi.org/10.1016/j.wasman.2017.03.046

[24] Latvian Renewable Energy federation. Biogas energy [Online]. [Accessed 15.05.2015]. Available: https://www.laef.lv/en/biogas//

[25] Putri D., Saputro R., Budiyono B. Biogas Production from Cow Manure. *International Journal of Renewable Energy Development* 2012:1:2:61–64. https://doi.org/10.14710/ijred.1.2.61-64

[26] Berglund Odhner P., Sárvári Horváth I., H. Mohseni Kabir M., Schabbauer A. Biogas from lignocellulosic biomass, 2012 [Online]. [Accessed 15.05.2015]. http://www.sgc.se/ckfinder/userfiles/files/SGC247.pdf.

[27] Tong H., Tong Y. W., Peng Y. H. A comparative life cycle assessment on mono- and co-digestion of food waste and sewage sludge. *Energy Procedia* 2019:158:4166–4171. https://doi.org/10.1016/j.egypro.2019.01.814

[28] Climate Change Connection. CO_2 equivalents [Online]. [Accessed 15.05.2015]. Available: https://climatechangeconnection.org/emissions/co2-equivalents/

[29] Brēmere I., Indriksone D., Klāvs G., Reķis J. Synergies and Conflicting Impacts of GHG Reduction Measures Recommendation Report. 2016 [Online]. [Accessed 15.05.2015]. Available: https://www.bef.lv/wp-content/uploads/2018/03/Rekomendacijas_zinojums_BEF.pdf

[30] Advertisements [Online]. [Accessed 15.05.2015]. Available: www.ss.com https://www.ss.com/

[31] Tariffs for municipal waste [Online]. [Accessed 15.05.2015]. Available: http://www.getlini.lv/en/private-clients

Ketija Bumbiere, M. sc. ing. She received the M. sc. degree from Riga Technical University and M. eng. degree from Vilnius Gediminas Technical University in 2020. She is working at Riga Technical University in the Institute of Energy Systems and Environment since 2020 as a research assistant. The main research areas are connected with biogas production, agriculture, renewable energy sources.
E-mail: ketija.bumbiere@rtu.lv

Jelena Pubule, Dr. sc. ing. Professor, Institute of Energy Systems and Environment, Riga Technical University. She received the Ph. D. degree from Riga Technical University in 2014. In the last 10 years Dr Pubule has mainly focused her research activity on the field of renewable energy sources, cleaner production, eco-efficiency and impact assessment. Jelena Pubule is an author and co-author of 22 publications indexed in Web of Science/Scopus data base, co-author of three scientific monographs. Has been involved in several international scientific projects. Jelena in an environmental engineering expert of Latvian Science Academy.
E-mail: jelena.pubule@rtu.lv
ORCID ID: https://orcid.org/0000-0002-0373-2675

Dagnija Blumberga, Dr. habil. sc. ing. Professor, director of Institute of Energy Systems and Environment, Riga Technical University. She is an expert in bioeconomy, cleaner production, circular economy, renewable energy, climate change, biotechnologies and other environmental engineering themes. Author of more than 400 scientific publications. Hirsch index 20. She has an experience in international projects as project leader and expert. Member of Professor Council of Riga Technical University, Member of Professor Council Of university of Latvia.
E-mail: dagnija.blumberga@rtu.lv
ORCID iD: https://orcid.org/0000-0002-9712-0804

Saulius Vasarevicius Dr., Professor, Vilnius Gediminas Technical University, Department of Environmental Protection and Water Engineering. He has Environmental Engineering Doctoral Degree (1995) from Vilnius Gediminas Technical University. Obtained Professors title in 2011. He has been part of academic staff Faculty of Environmental Engineering, Vilnius Gediminas Technical University from 1995. The main research area is waste management, soil treatment. He has participated in more than 50 international and local environmental projects (waste management, transport impact on environment, soil pollution investigations, air cleaning equipment, investigations of air pollution etc.). He is author of more than 100 publications. Address: Sauletekio al. 11, LT-10223, Vilnius, Lithuania.
E-mail: saulius.vasarevicius@vgtu.lt
ORCID iD: https://orcid.org/0000-0003-3799-8647

Vladimirs Kirsanovs, Dr. sc. ing. RTU IESE senior researcher defended his thesis in 2018 and received his doctorate in Environmental Engineering. He is working at Riga Technical University in the Institute of Energy Systems and Environment since 2011. The main research areas are connected with renewable energy technologies, biomass conversion technologies, energy system sustainability, flexibility and energy efficiency, sustainable transport. Vladimirs Kirsanovs has participated in more than 10 national and international scientific projects related to energy and environment. He is head of combustion research laboratory. He is a co-author of 26 scientific articles that are indexed in SCOPUS database, 2 monographs and 2 patents. Scientific articles are quoted 99 times and the h-index is 6. During the research, he has developed and applied 3 patent applications and co-authored 4 monographs.
E-mail: vladimris.kirsanovs@rtu.lv
ORCID iD: https://orcid.org/0000-0003-2501-5471

Agita Gancone, M. Sc. geogr. She received the M. Sc. geogr. degree in the University of Latvia, Faculty of Geography and Earth Sciences in 2002. She is PhD student in Riga Technical University. She is working at Ministry of Environmental Protection and Regional Development as senior expert in the field of GHG inventory preparation and coordination, GHG emission mitigation. The main research areas are connected with GHG emission calculation, mitigation and projections in different sectors including agriculture, evaluation of agriculture ecoefficiency, biogas production.
E-mail: agancone@inbox.lv

VALORIZATION METHODOLOGY FOR AGRICULTURE SECTOR CLIMATE CHANGE MITIGATION MEASURES

Environmental and Climate Technologies
2021, vol. 25, no. 1, pp. 944–954
https://doi.org/10.2478/rtuect-2021-0071
https://content.sciendo.com

Valorization Methodology for Agriculture Sector Climate Change Mitigation Measures

Agita GANCONE[1], Jelena PUBULE[2*], Dagnija BLUMBERGA[3]

[1–3]*Institute of Energy Systems and Environment, Riga Technical University, Riga, Latvia*

***Abstract* – Agriculture sector holds an essential role in Latvia's economy and play significant role in keeping rural areas as a habitable environment (approximately 32 % of the population lives in rural areas). The agricultural sector is responsible for 28.5 % (2018) of total non-European Union Emissions Trading System (non – EU ETS) greenhouse gas (GHG) emissions in Latvia. The largest part of emissions is related to agricultural soils (59.3 %) and enteric fermentation 32.6 % (mainly dairy and beef cattle). The GHG emissions trend of recent years shows a gradual and steady increase in GHG emissions for example between 2005 and 2018 +12.5 % and during the period 2013–2018 emissions increased by 2.12 %. According to Latvia's National Energy and Climate Plan 2021–2030 (NECP), total GHG emissions in the agricultural sector are expected to increase in the period from 2020 to 2030, mainly in the enteric fermentation and agricultural soil categories. To achieve determined targets for Latvia's non-EU ETS sector in 2030 and be on track to reach climate neutrality in 2050, the agricultural sector has to contribute to GHG emission mitigation. For the agricultural sector, improved food security and climate smart activities will be necessary to achieve GHG emission reduction. Existing policies and measures (WEM) as well as those which are included in the NECP as additional measures (WAM) were used to assess more suitable measures to move on climate smart agriculture (CSA), that could help to decrease GHG emissions at the farm and state level as well as is expected to contribute towards achieving the commitments in the plan. To achieve the aim of the study, a combination of the Delphi method together with multi-criteria analysis (MCA) is utilized to find a set of top GHG mitigation measures in the future. Results show that, in the future, the measure support the development of innovative technologies and solutions to promote resource efficiency in agriculture is essential to move on climate smart agriculture.**

***Keywords* – Climate smart agriculture; sustainable agriculture; Delphi method; GHG emissions; innovative technology; measures, mitigation**

1. INTRODUCTION

Latvia reduced GHG emissions from agriculture between 1990 and 2018 by 53 %, however in the latest years and future projections, a rising trend has developed [1]–[5]. In the agriculture sector, the increase in emissions is projected to be lower with implementation of additional policies and measures (WAM) scenario, e.g. support to precision farming practices, the reduction of nitrogen fertilizer use and biogas production than in the scenario with existing measures (WEM) 8.2 % [5]. According to the European Green Deal, it is planned to improve people's well-being and making Europe climate-neutral including a decrease of emissions while creating jobs [7]. To move on these ambitions, the European Commission proposes to revise relevant climate policies, for example, targets to reduce emissions in sectors outside

* Corresponding author.
E-mail address: jelena.pubule@rtu.lv

the EU ETS. To reach these ambitions, action will be required by all sectors of the economy, including agriculture nevertheless it is not so easy. One of the main challenges facing the agricultural sector is to provide food for increasing population at the same time reducing its influence on the climate and the environment [8]–[10]. According to the Intergovernmental panel on climate change (IPCC) Synthesis report (2015), the most profitable mitigation possibility is cropland and grazing land management as well as organic soils renewal in agriculture. Efficient mitigation and adaptation are related to implementation of policies and measures at several levels, including avoidance of use of less labour-intensive technologies in the agricultural sector [11], [12].

The Farm to Fork Strategy determines matters of sustainability of food as well the support granted to farmers. This Strategy includes the following main targets: agriculture of EU be organic 25 % by 2030, decrease the utilization of pesticides by 50 % until 2030, reduce use of fertilizers by 20 % by 2030, decrease loss of nutrients in soil at least 50 %, decrease antimicrobials use in agriculture and in aquaculture by 2030 by 50 %, create food labelling sustainable, reduce wastes of food by 50 % by 2030. All these mentioned initiatives include moving on climate smart agriculture (CSA) and contribute to the achievement of the sustainable development goals [13].

In literature there are more definitions related to CSA. In 2009, for the first time the CSA idea was initiated [14]. The term was reflected at the Hague Conference on Agriculture, Food Security and Climate Change by the Food and Agriculture Organization of the United Nations (FAO) in 2010 [15]. According to the FAO often used definition of CSA agriculture is that increases productivity in a sustainable way, increases resistant, decreases GHG, and increases the achievement of national food security and goals of development [16]. Lipper *et al.* also noted that definition and essential aim of CSA is the development and security of food [17] and productivity, adaptation, mitigation are pointed out as three interconnected activities to reach this aim. As well Lipper *et al.* [17] say that CSA could be explained as an approach for reorienting and transforming agricultural development taking into account climate change. However, A. Amin *et al.* stated that CSA can be determined as agricultural productivity growing in a sustainable way, building and adapting resilience to climate change, GHG emission reduction [18] as well as that it is a possibility to increase the policy, technical, and investment on the environment to get continual agricultural growth for food protection due to change of climate. As it is written by L. Lipper and D. Zilberman [14], CSA aims to provide comprehensive appropriate principles of agricultural management for food security due to climate change that would ensure a foundation upon which to build policy support as well as recommendations of organizations. FAO emphasizes three objectives of CSA (see Fig. 1.) [19], which can contribute to achieve the Sustainable Development goals.

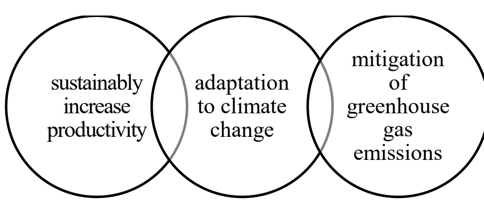

Fig.1. Objectives of climate smart agriculture.

It is recognized that to reach the objectives set in Fig. 1, agricultural production and food systems will need to use natural resources and other inputs in a more efficient way and become more resilient to change [20].

CSA is also mentioned in literature as an integrated approach to better adapt crops and livestock to climate change as well as agricultural methods, and thus reduce GHG emissions, considering also technological and environmental availability factors [21] at the same time taking into consideration the growing population for which there needs to be a guarantee in food security [22]. Thus, the emphasis is not simply on sustainable agriculture, but also on increasing agricultural productivity. The CSA is consistent with the vision of FAO and also supports the aim to turn agriculture into a more sustainable and efficient sector [15].

Smart agriculture is directed towards guiding the land supply and depending on its status, focusing on suitable growing parameters, such as material content, fertilizer, moisture – to ensure production of the appropriate crop that is in demand. The ways precision farming is implemented depends on the software used by sustainable entrepreneurs [23]. In the management of agriculture, reasonable intensification is necessary [24] and CSA is the solution [25]. Challenges related to climate change in the agricultural sector ask for acceptance of innovative methods in order to increase resilience, decrease influence, while supporting the productivity of the farm [26]. This set of activities has been also widely indicated by the FAO (2010).

Many policy instruments might be implemented for CSA practices adoption in agriculture sector, for example, regulatory and economic instruments (taxes, compensations) as well as on information-based instruments (e.g. Certification and labelling) [27]. The EU encourages Member States to include CSA principles in their Strategic Plans of Common Agriculture Policies through economic instruments.

Two methods (approaches) were used to enhance the methodology for agriculture sector to valorize climate change mitigation measures:

1. Delphi method;
2. Multi-criteria analysis.

Using the Delphi approach or technique in analysis of information it can be also deemed as Evaluate-Talk-Evaluate [28]. In literature the first use of the Delphi method is mentioned to have been used for technology projections and science and it was applied in economic trends, education and health [29].

2. METHODOLOGY

The objective of this study is the evaluation of a methodological approach for the mitigation GHG emissions from the agricultural sector in a way which is climate smart. To meet the aim of the study, the methodological concept used is the combination of the Delphi method together with multi-criteria analysis. The ETE approach is used to get expert opinions regarding existing and planned policies and measures for GHG emission reductions in the agricultural sector. The aim of the method is to collect the opinions and judgments of experts about issues in terms of possibilities in the future, likelihood and usefulness of implementation [30]. The approach of the method – the opinions of the experts are summarized in a process of communication by a planned group [28]. The method of Delphi is formulated on the idea that future predictions from a planned group of individuals are more precise if compared to unplanned groups [29]. The main characteristics of the Delphi method are: experts can remain anonymous, management of the survey is in several rounds, and feedback can be sought from the experts [30]. Experts were selected according to their competence. Nineteen GHG reduction measures with existing policies and measures and with additional policies and measures were included in the survey. These measures are taken from Latvia's latest submitted fourth biennial report (Latvia's BR4) to the United Nations Convention on Climate Change (UNFCCC) and from Latvia's National Energy and Climate

Plan 2021–2030 [31], [32]. Each of the experts was asked to assess these nineteen mitigation measures from an economic, engineering-technical, environmental/climate and social aspect.

The initial inputs of the experts are in the form of answers to the questionnaire and their comments on these answers. The questionnaire was sent to 25 experts with knowledge on the issue. Experts were asked to prepare their own opinion/prediction. All participants remained anonymous. 18 experts answered questionnaires in two rounds. Experts provided answers and additional descriptions and judgments.

Between these two rounds of the survey, a multi criteria analysis was performed, which allows for the prioritization and assessment of different measures from the economic, technical, environment/climate and social perspective. It is stated by Pubule *et al.*, that multi criteria analysis generally includes a weighted set of criteria [33]. To assess and find the most optimal scenario, TOPSIS (the Technique for Order of Preference by Similarity to Ideal Solution) was used, which was made by Hwang and Yoon [34]. The goal of this approach is to help in making a decision by grouping alternatives according to how they fit in with the best solution [35].

Additionally, experts were asked to consider first round replies taking into account the answers of other experts to get an overview/opinion regarding future projections for the most appropriate measures for GHG reduction and for a move to smart agriculture, where the efficient use of resources is one of the main goals.

The basic concept scheme used for the evaluation is shown in Fig. 2.

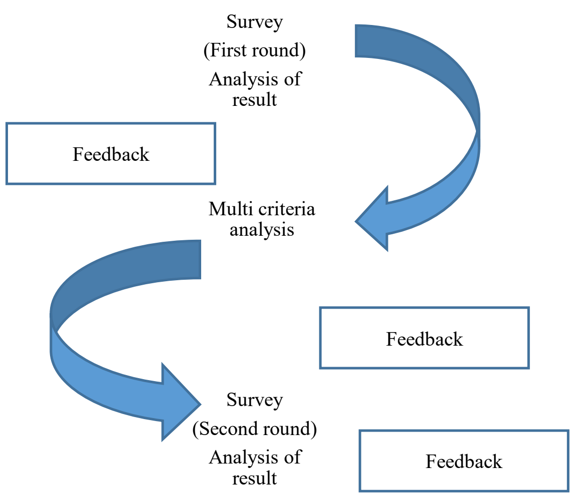

Fig. 2. Scheme of the used Delphi technique and TOPSIS for analysis.

A set of WEM and WAM policies and measures implemented, adopted and planned in Latvia's BR4 and NECP 2021–2030 focuses on developing programs and implementing measures on farms in different clusters to reduce GHG emissions from the agricultural sector. The following key policies and measures were reported in Latvia's BR4: increased land area of organic farming, legumes growing, support for advancing precision farming technologies and livestock feeding practices, promoting the reduced use of nitrogen fertilizers, including biogas production, maintenance of amelioration systems [36].

As the trend of GHG emissions from the agricultural sector shows an increase of emissions, the NECP includes the following to solve this problem: measures to promote the precise and efficient use of fertilizers, direct injection of slurry in soil; measures to improve soil fertility – maintenance of drainage systems, nitrogen sequestering crops as a part of crop rotation, under sowing grass, green fallow; measures that improve animal nutrition – improvement of feed quality, feed ration planning; measures to improve manure management systems – promotion of biogas production, organic dairy farming [37]. Unfortunately, a budget is not provided for all planned measures, therefore the implementation of these measures may be jeopardized. Research of Latvia's University of Life Sciences and Technologies related to GHG reduction measures are used for determination of appropriate additional measures and policies for Latvia's agriculture in the NECP [38]. Popluga D., Naglis–Liepa K. indicate that beneficial management practices are one of the globally most recognized methods to evaluate GHG emission potential and applied this approach to determine the following measures as the most appropriate – introduction of leguminous plants on arable land, nitrogen balance, lengthened grazing season, strategies of feeding, production of biogas [36], [39]–[41]. To evaluate the more eligible GHG emission decreasing measures for Latvia, a marginal abatement cost curve (MACC) was used [42].

Below are short descriptions of some of the GHG reduction measures and policies for WEM and WAM scenarios for the agricultural sector according to Latvia's BR4 and NECP [4], [3]:

– *Use of precision agriculture technologies in farms for crop growth to reduce use of nitrogen* – related with the use of nitrogen fertilizer reduction and thus reduction of nitrogen leaching and run-off. This measure reduces nitrous oxide emissions from agricultural soils;
– *Promotion of precision cattle feeding approach, including feeding plan development and support the use of good quality feed for increasing digestibility* – the aim of this implemented measure is to contribute to the use of good quality food for livestock thus decreasing methane emissions and increasing digestibility;
– *Introduction of leguminous plants on arable land* – related to the use of pulses as fodder and manure in the rotation of crops and thereby contributing to the use of nitrogen fertilizer reduction. This measure could reduce emissions of nitrous oxide from the use of inorganic N fertilizers and organic N fertilizers. Financial support is provided for the implementation of this measure according to national legislation;
– *Management of nitrate vulnerable territories* – related to the restriction of nitrogen usage and thus nitrogen leaching reduction as well as protection of water pollution from nitrates;
– *Water and soil protection requirements from pollution-related nitrates* – measure to restrict nitrogen usage and reduce nitrogen leaching. This measure reduces indirect N_2O emissions from managed agricultural soils;
– *Crop fertilization plans in vulnerable zones* –measure for farmers in highly vulnerable areas who have an area of 20 and more hectares and grows potatoes, vegetables and are required to document the field history for at least three years, if fertilizers are used.
– *Requirements for manure storage and spreading* – related to requirements of manure storage outside the animal shed and is for farms in vulnerable territories;
– *Maintenance and modernization of amelioration systems on agricultural land* – measure reduces indirect N_2O emissions from N leaching and run-off from agricultural land and is used for implementation in croplands on mineral soils, where, due to unfriendly circumstances, are not easy to get high yields, especially in the spring time, which are induced by drainage systems wearing. Financial support for renovation of a

drainage system is made according to established national legislation. Modernization of amelioration systems on agricultural land is planned to increase arable land area with improved and maintained amelioration systems, thereby reducing nitrogen leaching and run-off from agriculture land;

- *Promotion of biogas production* –measure for usage of bioresources (mainly or only manure) to produce biogas which is used to generate electrical and/or thermal energy. By implementing this measure, the manure is efficiently used, the odor is reduced and a high-quality fertilizer called digestate is obtained;
- *Organic farming land area increase* – related to methods of farming with inorganic nitrogen fertilizers use reduction and leaching, increased biodiversity and environmentally favorable impact on nature;
- *Extensified crop rotation* – related with use of green manure in rotation of crops and promoting organic dairy farming. The main aim of the measure is to promote transition of small and medium-sized conventional dairy farms to the organic farming system, thus facilitating low emission dairy farming;
- *Support for fertilization planning* – the main aim of the measure is to expand arable land and increase the number of medium-sized crop and livestock farms where fertilization planning and practical implementation that is based on knowledge about agrochemical properties of soil has not been done previously;
- *Promote inclusion of leguminous plants in crop rotation for nitrogen fixation* – the main aim of the measure is to expand arable land and increase number of farms where leguminous plants are included in crop rotation thus contributing to atmospheric nitrogen fixation and reduction of application of inorganic nitrogen fertilizers;
- *Promote and support for precision application of inorganic nitrogen fertilizers* – related to expanding arable land and increasing number of farms where precision technologies for application of inorganic nitrogen fertilizers are used in the planning of fertilizer schemes and spreading;
- *Promote and support for direct incorporation of organic fertilizers into the soil* (using specific technology) – related to expanding arable land where organic fertilizers are directly incorporated into the soil thus promoting more efficient use of organic fertilizers;
- *Promote feed ration planning* – related to increased number of cows the feed rations of which are balanced for reduced crude protein level without loss in milk production;
- *Promote improvement of feed quality* – related to increasing the number of cows who are fed with feed (in this measure special attention is paid to hay, hay silage, grass silage) with high digestible energy (i.e. digestible energy is more than 68 %);
- *Promote biogas and biomethane production and biomethane use* – related to ensure the installation of biogas production and biogas purification (biomethane production) facilities on farms that have not yet had biogas production and purification facilities;
- *Support the development of innovative technologies and solutions to promote resource efficiency, GHG reduction/CO_2 sequestration in agriculture* – measure whereby support will be provided for the development of the new technologies and innovative solutions for GHG emission reduction and increase of CO_2 removal. Unfortunately, the financial source is not indicated.

3. RESULTS

This paper introduced a way of measuring policies and measures in the agricultural sector for evaluation GHG reduction based on the Delphi method and multi criteria analysis where the criteria taking into account include: economic, engineering-technical, environmental/climate and social. Criteria weights were determined by experts.

TABLE 1. WEIGHTED NORMALISED MATRIX

Measures	Economical	Technical	Climate	Social
Promote and support for precise application of inorganic nitrogen fertilisers	0.075	0.070	0.073	0.022
Support for fertilisation planning	0.088	0.074	0,074	0.023
Requirements for manure storage and spreading	0.063	0.065	0,075	0.022
Promote and support for direct incorporation of organic fertilisers into the soil	0.060	0.064	0.070	0.023
Use of precision agriculture technologies in farms for crop growing to reduce use of nitrogen	0.074	0.068	0.072	0.022
Promote inclusion of leguminous plants in crop rotation for nitrogen fixation	0.073	0.072	0.071	0.024
Support and promote intercropping system in cereal growing	0.065	0.063	0.060	0.021
Support and promote green fallow introduction before winter crop sowing	0.064	0.067	0.057	0.022
Promote organic dairy farming (low emission dairy farming)	0.061	0.071	0.068	0.027
Promote precision cattle feeding approach, including feeding plan development and support good quality use of feed to increase digestibility	0.087	0.079	0.072	0.023
Promote improvement of feed quality for cattle farms	0.078	0.074	0.070	0.024
Promote biogas production	0.060	0.064	0.072	0.024
Promote biogas and biomethane production and biomethane use	0.060	0,062	0,073	0,025
Maintain and modernise amelioration systems on agricultural land	0.070	0.066	0.061	0.023
Promote the conservation of perennial grassland on livestock farms	0.057	0.072	0.068	0.023
Management of nitrate vulnerable territories	0.063	0.067	0.057	0.019
Water and soil protection requirements from pollution-related nitrates	0.059	0.062	0.064	0.022
Create a map of the distribution of peat soils on agricultural land	0.066	0.067	0.070	0.022
Support the development of innovative technologies and solutions to promote resource efficiency, GHG reduction/CO_2 sequestration in agriculture	0.072	0.074	0.074	0.025

Based on the results of the first round of the survey, TOPSIS was used. A normalized and weighted matrix for decision making of the evaluation of measures to reduce GHG emissions in the agricultural sector are shown in Table 1 and Fig. 3.

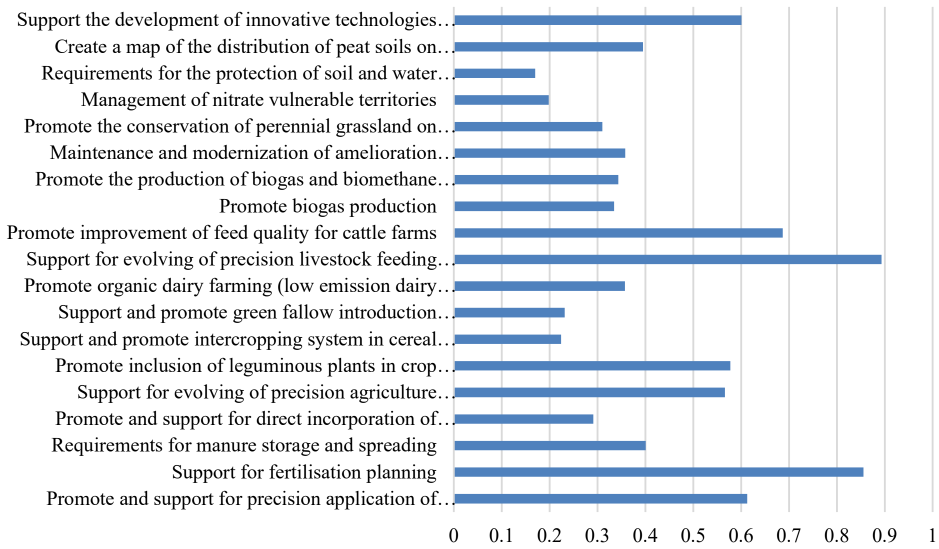

Fig. 3. Ranking of measures by TOPSIS.

The obtained results showed that, taking into account all criteria, the most effective measures are: promotion of precision cattle feeding approach, including the development of feeding plans and support good quality use of feed to increase digestibility; support the development of innovative technologies (e.g. the development of information and communication technologies [43]) and solutions to promote resource efficiency; GHG reduction/CO_2 sequestration in agriculture.

The first round of survey shows that, according to experts, there are farmers that do not trust new technologies and would like to work as usual. While mostly the young farmers are ready to change and move towards smart technologies thereby also on smart agriculture, support for fertilisation planning, promote improvement of feed quality for cattle farms.

Taking into account the results of the multi-criteria analysis, policies and measures were grouped in order of importance (see Table 2) and then asked for experts to forecast the leader of future measures for GHG emission reduction in the agricultural sector taking into account only the leading measures.

According to the second round of the survey, all involved experts forecasted that in the future the complex measure *Support the development of innovative technologies and solutions to promote resource efficiency, GHG reduction/CO_2 sequestration* will be at the top of all measures in the agricultural sector. This measure is forecasted to be one of the core measures to be developed within the implementation of sustainable and smart agriculture in the future. According to the view of experts in this survey, this measure could contribute to reduce GHG emissions considering sustainable agricultural management, animal rearing techniques, as well as nutrient management improvement, including precision farming.

TABLE 2. GROUPED POLICIES AND MEASURES BY PRIORITY

Priority	Policies and measures				
Leader (0.6–0.9)	Promote precision cattle feeding approach, including feeding plans development and support good quality use of feed to increase digestibility	Support for fertilisation planning	Promote improvement of feed quality for cattle farms	Promote and support for precision application of inorganic nitrogen fertilisers	**Support the development of innovative technologies and solutions to promote resource efficiency, GHG reduction/CO_2 sequestration**
Strong (0.4–0.6)	Promote inclusion of leguminous plants in crop rotation for nitrogen fixation	Use of precision agriculture technologies in farms for crop growth to reduce use of nitrogen	Requirements for manure storage and spreading		
Moderate (0.2–0.4)	Create a map of the distribution of peat soils on agricultural land	Promote organic dairy farming (low emission dairy farming)	Promote biogas and biomethane production and biomethane use	Promote the conservation of perennial grasslands on livestock farms	Support and promote intercropping system in cereal growing
	Maintain and modernise amelioration systems on agricultural land	Promote organic dairy farming (low emission dairy farming)	Promote biogas production	Promote and support for direct incorporation of organic fertilisers into the soil	Support and promote green fallow introduction before winter crop sowing
Modest (0–0.2)	Management of nitrate vulnerable territories	Water and soil protection requirements from pollution related nitrates			

4. CONCLUSION AND DISCUSSIONS

In this study key policies and measures within WEM and WAM scenarios for the agricultural sector were used in accordance with Latvia's BR4 and NECP to evaluate top GHG measures for emission reductions to mitigate climate change in the future. For this analysis, a combination of two approaches: Delphi method and MCA were used. The opinion of experts about the most appropriate measures for decreasing emissions was gathered in two rounds using the Delphi approach. A combination of the Delphi method and MCA allowed to range the measures in order of importance and then, in the second round, to ask experts to evaluate the most significant measure (from those analyzed) to combat climate change. The results show that, in the future, the measure *Support the development of innovative technologies and solutions to promote resource efficiency, GHG reduction / CO_2 sequestration in agriculture* is essential to move on climate smart agriculture and net-zero emissions balance in 2050. At the same time, it should be noted that important environmental protection measures are management of nitrate vulnerable territories and water and soil protection requirements from pollution related nitrates which were grouped as modest priority. Making more intelligent/innovative farming will help to improve quality of products and agriculture sustainability as well as decrease costs. To implement this measure within the daily life of farmers, more training courses are necessary and support from the government is also needed. Therefore, to stimulate innovative technologies for decreasing GHG emissions and help farmers adapt to climate change a largescale transformative approach, including change in agriculture policy is needed. It is important that the creation and development of new technologies, higher value-added products and services requires the establishment of carbon farming practices, as well as investments in research as well. Furthermore, to achieve GHG emission reduction in agriculture sector without people changing behavior is not possible therefore activity in this field is very essential and policy makers should focus much more on it.

Usage of the combination of the above mentioned methods in policy planning could support policy makers with better results through already prescreened GHG mitigation measures for agriculture sector.

ACKNOWLEDGEMENT

This research is funded by the Ministry of Economics of the Republic of Latvia, project "Energy and climate modelling towards net zero emissions", project No. VPP-EM-2018/NEKP-0001.

REFERENCES

[1] Official statistics of Latvia. Official statistics portal. Population number, its changes and density. Population of rural and urban territories [Online]. [Accessed 03.01.2021]. Available: https://stat.gov.lv/en/statistics-themes/population/population-number/247-population-number-its-changes-and-density
[2] Ministry of Economy. Latvijas ekonomikas attīstības pārskats (Latvian economic development report.). Rīga: MoE, 2019. (in Latvian)
[3] European Commission. Commission staff working document. Commission recommendations for Latvia's CAP strategic plan. SWD (2020) 386 final. Brussels: European Commission, 2020.
[4] Gancone A., *et al.* Latvia's National GHG Inventory report 1990 – 2018 to the UNFCCC. Riga: VARAM, 2020.
[5] Latvia's National Energy and Climate plan 2021. – 2030. Riga: Cabinet of Ministers, 2020.
[6] Gancone A., *et al.* Latvia's forth Biennial Report to the UNFCCC. Riga: VARAM, 2019.
[7] European Commission. Communication from the commission – The European Green Deal. COM/2019/640 final. Brussels: European Commission, 2019.
[8] Fusco G., *et al.* How to Improve the Diffusion of Climate-Smart Agriculture: What the Literature Tells us. *Sustainability* 2020:12(12):5168. https://doi.org/10.3390/su12125168
[9] Muizniece I., *et al.* Circular Economy and Bioeconomy Interaction Development as Future for Rural Regions. Case Study of Aizkraukle Region in Latvia. *Environmental and Climate Technologies* 2019:23(3):129–146. https://doi.org/10.2478/rtuect-2019-0084
[10] Pubule J., *et al.* Sectoral Greenhouse Gas Emission Mitigation Possibilities. Why Broad Spectrum of Indicators is Applied. *Energy Procedia* 2017:113:377–381. https://doi.org/10.1016/j.egypro.2017.04.015
[11] Brazdausks P., *et al.* Evaluation of cellulose content in hemp shives after salt catalyzed hydrolysis. *Energy Procedia* 2017:128:297–301. https://doi.org/10.1016/j.egypro.2017.08.316
[12] IPCC. Climate change 2014. Synthesis report. Geneva: IPCC, 2015.
[13] European Commission. A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. COM/2020/381 final. Brussels: European Commission, 2020.
[14] Lipper L., Zilberman D. A Short History of the Evolution of the Climate Smart Agriculture Approach and Its Links to Climate Change and Sustainable Agriculture Debates. In Lipper L., McCarthy N., Zilberman D., Asfaw S., Branca G. (eds) *Climate Smart Agriculture*. Natural Resource Management and Policy 2018:52:13–30. https://doi.org/10.1007/978-3-319-61194-5_2
[15] Food and agriculture organization of the United Nations. CLIMATE-SMART AGRICULTURE Sourcebook. Rome: FAO, 2013.
[16] "Climate-Smart" Agriculture Policies, Practices and Financing for Food Security, Adaptation and Mitigation Food and Agriculture Organization of the United Nations. Rome: FAO, 2010.
[17] Lipper L., *et al.* Climate-smart agriculture for food security. *Nature Climate Change* 2014:4:1068–1072. https://doi.org/10.1038/nclimate2437

[18] Amin A., *et al.* Climate Smart Agriculture: an approach for sustainable food security. *Agricultural Research Communication* 2015:2(3):13–21.
[19] Climate Smart Agriculture [Online]. [Accessed: 22.03.2021]. Available: https://www.iaea.org/topics/climate-smart-agriculture
[20] Campbell B. M., *et al.* Sustainable intensification: What is its role in climate smart agriculture? *Current Opinion in Environmental Sustainability* 2014:8:39–43. https://doi.org/10.1016/j.cosust.2014.07.002.
[21] Pagliacci F., *et al.* Drivers of farmers' adoption and continuation of climate-smart agricultural practices. A study from northeastern Italy. *Science of The Total Environment* 2020:710:136345. https://doi.org/10.1016/j.scitotenv.2019.136345
[22] Climate-Smart Agriculture. World Bank [Online]. [Accessed: 22.03.2021]. Available: https://www.worldbank.org/en/topic/climate-smart-agriculture
[23] Long T. B., Blok V., Coninx I. The diffusion of climate-smart agricultural innovations: Systems level factors that inhibit sustainable entrepreneurial action. *Journal of Cleaner Production* 2019:232:993–1004. https://doi.org/10.1016/j.jclepro.2019.05.212
[24] Tesfai M., *et al.* Transition towards bio-based economy in small-scale agriculture in Sub-Saharan Africa through sustainable intensification. The Bioeconomy Approach. Constraints and Opportunities for Sustainable Development. London: Routledge, 2020.
[25] Senyolo M. P., *et al.* How the characteristics of innovations impact their adoption: an exploration of climate-smart agricultural innovations in South Africa. *Journal of Cleaner Production* 2018:172:3825–3840. https://doi.org/10.1016/j.jclepro.2017.06.019
[26] Khatri-Chhetri A., *et al.* Stakeholders prioritization of climate-smart agriculture interventions: Evaluation of a framework. *Agricultural Systems* 2019:174:23–31. https://doi.org/10.1016/j.agsy.2019.03.002
[27] Long T. B., Blok V., Coninx I. Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy. *Journal of Cleaner Production* 2016:112(1):9–21. https://doi.org/10.1016/j.jclepro.2015.06.044.
[28] Harold A. L., Turoff M., Helmer O. *The Delphi Method Techniques and Applications*. Boston: Addison-Wesley, 2002.
[29] Green R.A. The Delphi Technique in Educational Research. *Education Theory and Practice, Educational Research, Research Methods* 2014:4(2). https://doi.org/10.1177/2158244014529773
[30] Dick S., *et al.* The Delphi Method Research Strategy in Studies of Information Systems. *Communications of the Association for Information Systems* 2015:37:31–63. https://doi.org/10.17705/1CAIS.03702
[31] San-Jose L., Retolaza J. L. Is the Delphi method valid for business ethics? A survey analysis. *European Journal for Futures Research* 2016:4:19. https://doi.org/10.1007/s40309-016-0109-x
[32] Rowe G., Wright G., Expert Opinions in Forecasting. Role of the Delphi Technique. *Principles of Forecasting: A Handbook of Researchers and Practitioners.* In Armstrong J.S. (eds) *Principles of Forecasting. International Series in Operations Research & Management Science* 2001:30:125–144. https://doi.org/10.1007/978-0-306-47630-3_7
[33] Pubule J., *et al.* Finding an optimal solution for biowaste management in the Baltic States. *Journal of Cleaner Production* 2015:88:214–223. https://doi.org/10.1016/j.jclepro.2014.04.053.
[34] Hwang C. L., Yoon K. *Multiple Attribute Decision Making*. Springer, 1981. https://doi.org/10.1007/978-3-642-48318-9
[35] Tzeng G. H., Huang J. J. *Multiple Attribute Decision Making: Methods and Applications*. Chapman and Hall/CRC, 2011. https://doi.org/10.1201/b11032
[36] UNFCCC. Report on the technical review of the fourth biennial report of Latvia. Bonn: UNFCCC, 2020.
[37] Bumbiere K., *et al.* Carbon balance of biogas production from maize in Latvian conditions. *Agronomy Research* 2021:19(1):687–697. https://doi.org/10.15159/AR.21.085
[38] Rivza P., *et al.* Greenhouse gas emission reduction opportunities with climate-friendly agriculture and forestry in Latvia. Jelgava: LLU, 2018. (in Latvian)
[39] Popluga D., Naglis-Liepa K. Evaluation of measures for mitigation of greenhouse gas emissions suitable for Latvian agriculture. *Engineering for Rural Development* 2015:584–589.
[40] Bumbiere K., *et al.* Ranking of Bioresources for Biogas Production. *Environmental and Climate Technologies* 2020:24(1):368–377. https://doi.org/10.2478/rtuect-2020-0021.
[41] Bumbiere K., Pubule J., Blumberga D. What Will Be the Future of Biogas Sector? *Environmental and Climate Technologies* 2021:25(1):295–305. https://doi.org/10.2478/rtuect-2021-0021.
[42] Naglis-Liepa K., Popluga D. Integrated impact assessment of agricultural GHG abatement measures.2018. *Proceedings of the 2018 International Conference "Economic science for rural development"* 2018:49:77–83. https://doi.org/10.22616/ESRD.2018.121
[43] Oliveira M. F., *et al.* Innovations in Sustainable Agriculture: Case Study of Lis Valley Irrigation District, Portugal. *Sustainability* 2019:11(2):331. https://doi.org/10.3390/su11020331.

TOWARDS CLIMATE NEUTRALITY VIA SUSTAINABLE AGRICULTURE IN SOIL MANAGEMENT

Environmental and Climate Technologies
2022, vol. 26, no. 1, pp. 512–524
https://doi.org/10.2478/rtuect-2022-0039
https://content.sciendo.com

Towards Climate Neutrality via Sustainable Agriculture in Soil Management

Agita GANCONE[1]*, Ruta VIZNERE[2], Daina KALEJA[3], Jelena PUBULE[4], Dagnija BLUMBERGA[5]

[1–5]*Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, Latvia*

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 to reducing GHG

* Corresponding author.
E-mail address: agancone@inbox.lv

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.

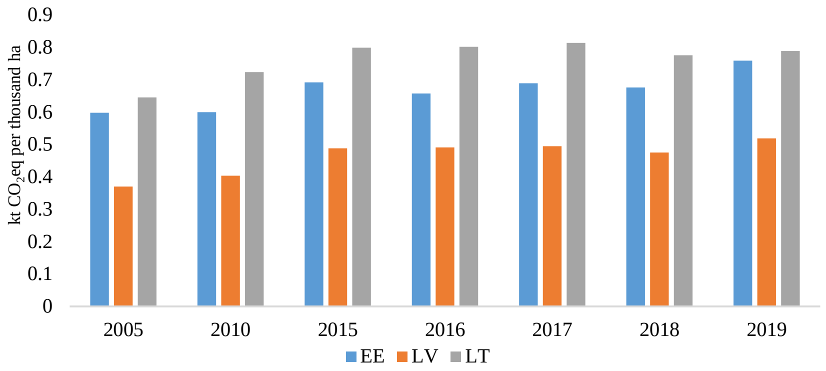

Fig. 1. GHG emissions per agricultural area (kilotons CO_2 eq. per thousand hectares) [12].

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]. 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.

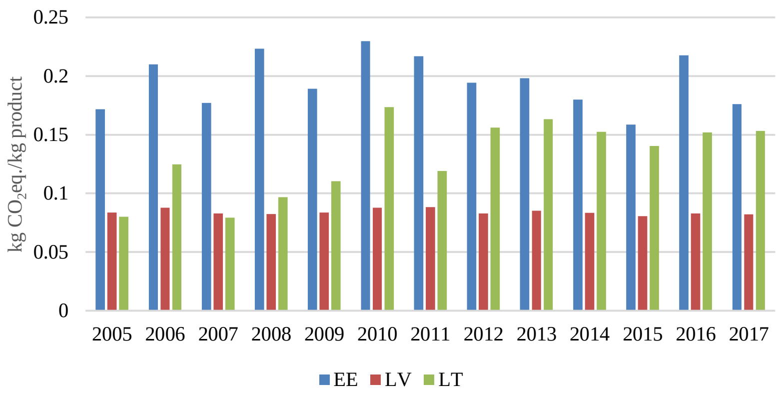

Fig. 2. GHG emission intensity [19].

Crops play an essential role in sustainable food, feed, fiber 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 analyzed 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, fibers, 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.

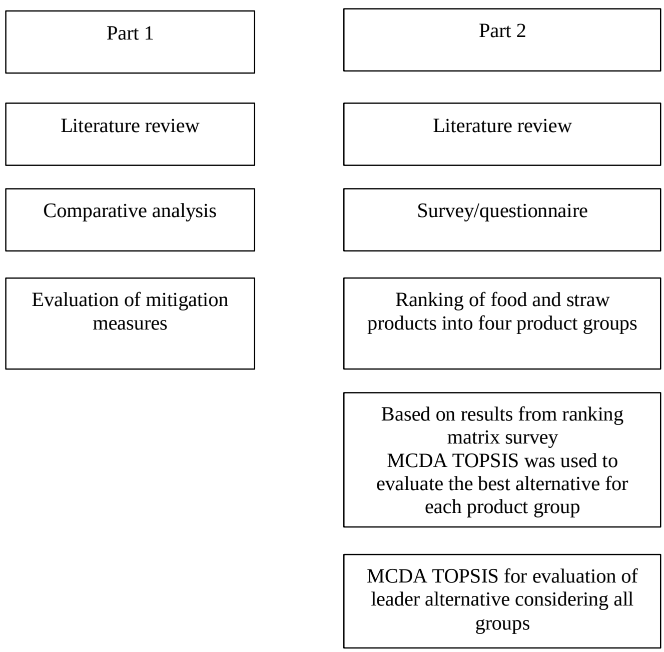

Fig. 3. Framework of methodology.

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.).

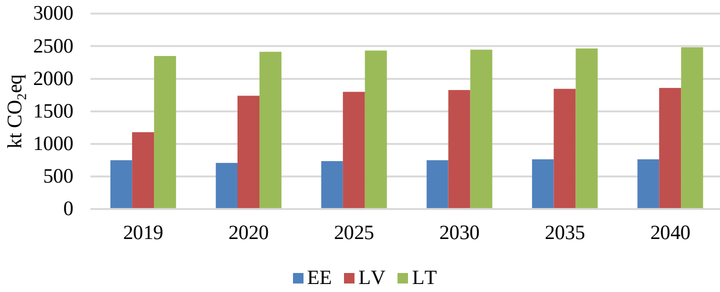

Fig. 4. GHG emissions (historical and projected) from agricultural soils [13]–[18].

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

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, taking into account 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

1. Each food group,
2. Pharmaceutical products,
3. Transport,
4. Straw product group are displayed in Fig. 5.

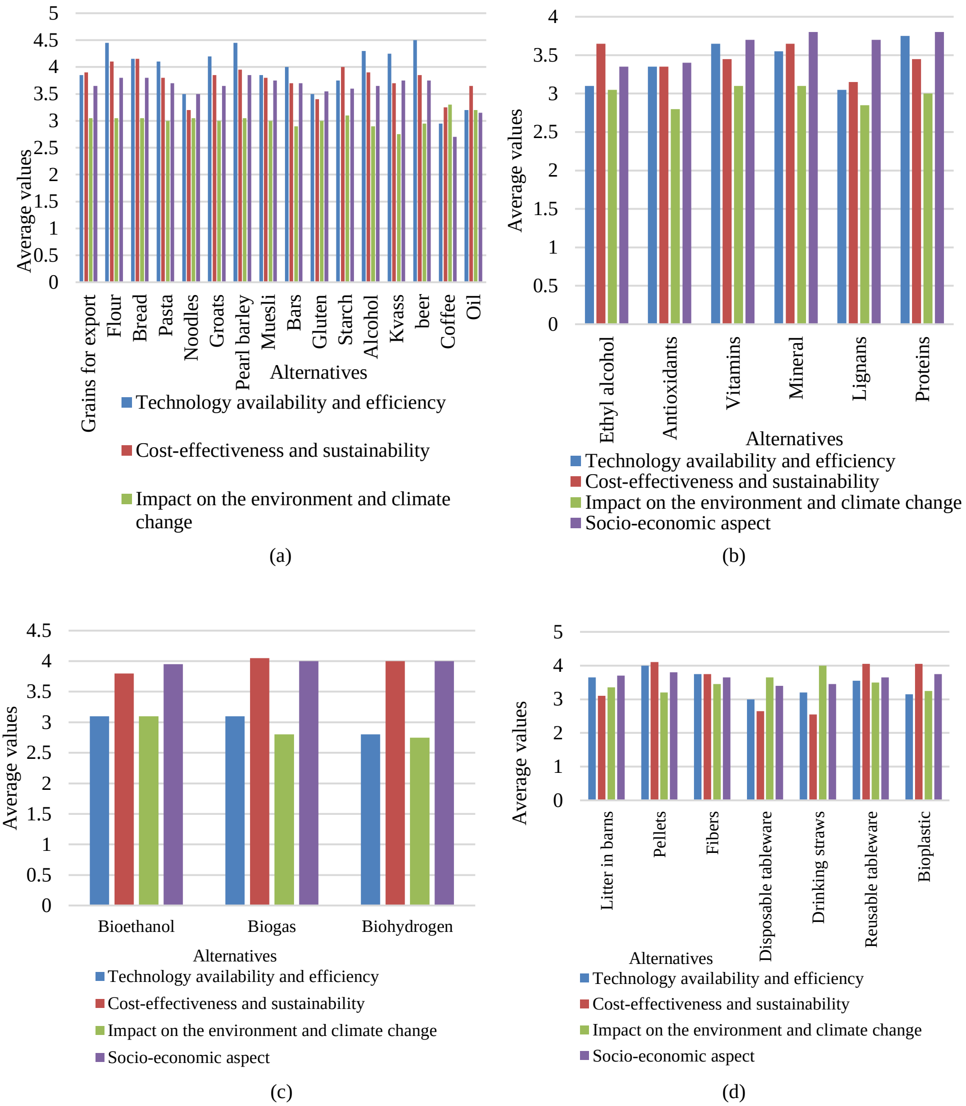

Fig. 5. Average rating of respondents for the groups of a) food; b) pharmaceutical; c) straw products and d) the transport sector.

According to data in Fig. 5:

1. 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;
2. b) shows data obtained from the group of pharmaceutical products represented by six alternatives – ethyl alcohol, antioxidants, vitamins, minerals, lignans and proteins;
3. c) shows the results for the transport products with its three alternatives – bioethanol, biogas and biohydrogen;
4. d) shows the results for the straw product group with its seven alternatives – barn litter, pellets, fibers, 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, fibers 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, fibers
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.

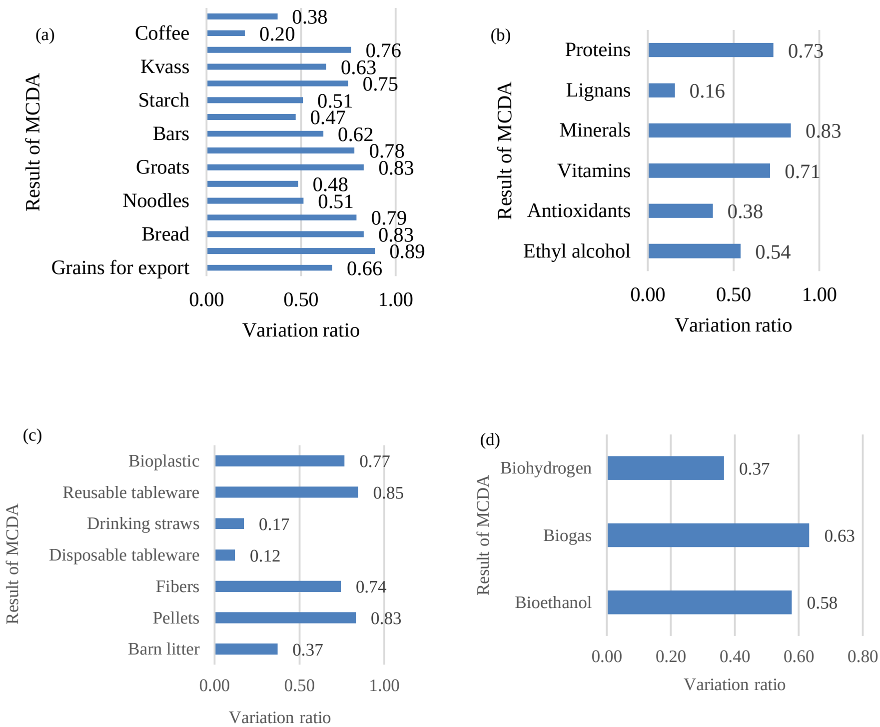

Fig. 6. MCDA TOPSIS analysis for the groups of a) food; b) pharmaceutical; c) transport sector and d) straw products.

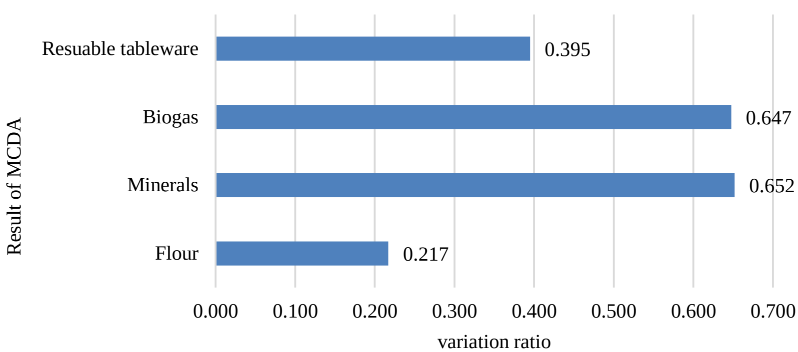

Fig. 7. Summary results of the alternatives with the highest added value for each assessed group.

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.

ACKNOWLEDGEMENT

This research is funded by the Latvian Council of Science, project CO2 Deal: Effective Valorisation of CO_2 for Decarbonised Regional Development, project No. lzp-2020/1-0302.

REFERENCES

[1] Communication from the commission to the European parliament, the European council, the council, the European economic and social committee and the committee of the regions, The European Green Deal. COM/2019/640 final. Brussels: EC, 2019.

[2] Communication from the commission to the European parliament, the European council, the council, the European economic and social committee and the committee of the regions, A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. COM/2020/381 final. Brussels: EC, 2020.

[3] COM (2020) 80 final, Proposal for a Regulation of the European Parliament and of the Council establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law). Brussels: EC, 2020.

[4] COM (2020) 98 final, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A new Circular Economy Action Plan. Brussels: EC, 2020.

[5] Buzkova R. Own Resources in the Light of European Council Conclusions on the MFF and Next Generation EU. *Financial Law Review* 2020:20(4):22–34. https://doi.org/10.4467/22996834FLR.20.018.13090
[6] Proposal for a Regulation amending Regulation (EU) 2018/842 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement. Brussels: EC, 2021.
[7] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulations (EU) 2018/841 as regards the scope, simplifying the compliance rules, setting out the targets of the Member States for 2030 and committing to the collective achievement of climate neutrality by 2035 in the land use, forestry and agriculture sector, and (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review. Brussels: EC, 2021.
[8] COMMISSION STAFF WORKING DOCUMENT. Analysis of links between CAP Reform and Green Deal. Brussels: EC, 2020.
[9] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official Journal of the European Union* 2009:L 140/16.
[10] Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency. *Official Journal of the European Union* 2018:L 328/210.
[11] European Commission. EU Agriculture in Numbers: Performance on the nine specific objectives of the CAP. Brussels, 2020.
[12] Eurostat/ Eurostat database [Online]. [Accessed 15 March 2022]. Available: https://ec.europa.eu/eurostat/data/database
[13] United Nations Climate Change. Estonia Fourth Biennial Report under the United Nations Framework Convention on Climate Change. Charlotte: UNCC, 2019.
[14] United Nations Climate Change. Latvian Fourth Biennial Report under the United Nations Framework Convention on Climate Change. Charlotte: UNCC, 2019.
[15] United Nations Climate Change. Lithuania Fourth Biennial Report under the United Nations Framework Convention on Climate Change. Charlotte: UNCC, 2020.
[16] United Nations Climate Change. FCCC/TRR.4/EST. Report on the technical review of the fourth biennial report of Estonia. Charlotte: UNCC, 2020.
[17] United Nations Climate Change. FCCC/TRR.4/LVA. Report on the technical review of the fourth biennial report of Latvia. Charlotte: UNCC, 2020.
[18] United Nations Climate Change. FCCC/TRR.4/LTU. Report on the technical review of the fourth biennial report of Lithuania.Charlotte: UNCC, 2020.
[19] Food and Agriculture Organization of the United Nations. FAO database [Online]. [Accessed 15 March 2022]. Available: https://www.fao.org/faostat/en/#home
[20] Gaurav N., *et al.* The utilisation of bioresources for sustainable biofuels: A Review. *Renewable and Sustainable Energy Reviews* 2017:73:205–214. https://doi.org/10.1016/j.rser.2017.01.070
[21] Brazdausks P., *et al.* Evaluation of cellulose content in hemp shives after salt catalyzed hydrolysis. *Energy Procedia* 2017:128:297–301. https://doi.org/10.1016/j.egypro.2017.08.316
[22] Pubule J., *et al.* Analysis of the environmental impact assessment of power energy projects in Latvia. *Management of Environmental Quality* 2012:23(2):190–203. https://doi.org/10.1108/14777831211204930
[23] Hayes R. C., *et al.* Perennial cereal crops: An initial evaluation of wheat derivatives. *Field Crops Research* 2012:133:68–89. https://doi.org/10.1016/j.fcr.2012.03.014
[24] Marti A., *et al.* Structural characterisation of proteins in wheat flour doughs enriched with intermediate wheatgrass (Thinopyrum intermedium) flour. *Food Chemistry* 2016:194:994–1002. https://doi.org/10.1016/j.foodchem.2015.08.082
[25] Monforti F., *et al.* Optimal energy use of agricultural crop residues preserving soil organic carbon stocks in Europe. *Renewable and Sustainable Energy Reviews* 2015:44:519–529. https://doi.org/10.1016/j.rser.2014.12.033
[26] Monti M., *et al.* Cereal/grain legume intercropping in rotation with durum wheat in crop/livestock production systems for the Mediterranean farming system. *Field Crops Research* 2019:240:23–33. https://doi.org/10.1016/j.fcr.2019.05.019
[27] Chuang Y.-S., *et al.* Fermentative bioenergy production from distillers grains using mixed microflora. *International Journal of Hydrogen Energy* 2012:37(20):15547–15555. https://doi.org/10.1016/j.ijhydene.2012.01.035
[28] United Nations Climate Change. FCCC/CP/2011/9/Add.1, Decision 2/CP.17: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention. Charlotte: UNCC, 2011.
[29] Opricovics S., Tzeng G. H. Compromise solution by MCDM methods:A comparative analysis of VIKOR and TOPSIS. *European Jornal of Operational Research* 2004:156(2):445–455. https://doi.org/10.1016/S0377-2217(03)00020-1
[30] Stocker T. F., *et al.* Climate Change 2013. The Physical Science Basis. Summary for Policymakers, Technical Summary and Frequently Asked Questions. Geneva: IPCC, 2013.
[31] German R., *et al.* Agricultural climate mitigation policies and measures. ETC/CME Eionet Report/6/2021. Boeretang: European Topic Centre on Climate, 2021.

[32] Ahmed J., *et al.* Agriculture and climate change. Reducing emissions through improved farming practices. Stockholm: McKinsey & Company, 2020.
[33] Popluga D., Kreišmane Dz. SEG emisijas samazinoši pasākumi (Measures to reduce GHG emissions). 2019 [Online]. [Accessed 5 March 2022]. Available: https://www.llu.lv/lv/seg-emisijas-samazinosi-pasakumi (in Latvian)
[34] Muñoz R., *et al*. Estimation of the lifespan of agricultural tractors using a diffusion model at the aggregate level. *Ciencia e investigación agrarian* 2012:39(3):557–562. https://doi.org/10.4067/S0718-16202012000300014
[35] Jiafa Luo *et al.* Nitrous oxide and greenhouse gas emissions from grazed pastures as affected by the use of nitrification inhibitor and restricted grazing regime. *Science of the Total Environment* 2013:465:107–114. https://doi.org/10.1016/j.scitotenv.2012.12.075
[36] Pedro Pellegrini *et al.* Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution. *Proceedings of the National Academy of Sciences* 2018:115(10):2335–2340. https://doi.org/10.1073/pnas.1717072115
[37] Kanter D., Zhang X., Mauzerall D. L. Reducing Nitrogen Pollution while Decreasing Farmers' Costs and Increasing Fertilizer Industry Profits. *Journal of Environmental Quality* 2015:44(2):325–335. https://doi.org/10.2134/jeq2014.04.0173
[38] Latvia University of Life Sciences and Technologies. Latvijas lauksaimniecības siltumnīcefekta gāzu un amonjaka emisiju, kā arī CO_2 piesaistes (aramzemēs un zālājos) robežsamazinājuma izmaksu līkņu (MACC) pielāgošana izmantošanai lauksaimniecības, vides un klimata politikas veidošanā (Adaptation of Latvia's greenhouse gas and ammonia emissions as well as CO2 capture (arable land and grasslands) marginal cost reduction curves (MACC) for use in agricultural, environmental and climate policy-making.). Jelgava: LLU, 2019. (in Latvian)
[39] MacLeod M., *et al.* Cost-Effectiveness of Greenhouse Gas Mitigation Measures for Agriculture: A Literature Review. OECD Food, Agriculture and Fisheries Papers. Paris: OECD Publishing, 2015:89. https://doi.org/10.1787/5jrvvkq900vj-en
[40] Hoglund-Isaksson L., *et al.* EU low carbon roadmap 2050: Potentials and costs for mitigation of non-CO2 greenhouse gas emissions. *Energy Strategy Reviews* 2012:1(2):97–108. https://doi.org/10.1016/j.esr.2012.05.004
[41] Bumbiere K., *et al*. Ranking of Bioresources for Biogas Production. *Environmental and Climate Technologies* 2020:24(1):368–377. https://doi.org/10.2478/rtuect-2020-0021
[42] De Cara S., Jayet P.-A. Marginal abatement costs of greenhouse gas emissions from European agriculture, cost-effectiveness, and the EU non-ETS Burden Sharing Agreement. *Ecological Economics* 2010:70(9):1680–1690. https://doi.org/10.1016/j.ecolecon.2011.05.007