RIGA TECHNICAL UNIVERSITY

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TRANSITION TOWARDS RESULT-BASED AGRICULTURE SECTOR AND CLIMATE TARGETS

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
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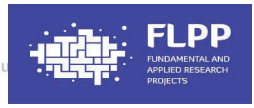

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on 3 Month 2022 at 14.00 at the Faculty of Electrical and Environmental Engineering of Riga Technical University, 12k-1 Āzenes Street, Room 115.

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Name Surname ……. (signature)
Date: ……

The Doctoral Thesis has been written in English. It consists of an Introduction, 3 chapters, Conclusions, 29 figures, 24 tables; the total number of pages is 164. The Bibliography contains 192 titles.

CONTENTS

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 between1.5 °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, 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.

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. 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. 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 general objectives 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 and recommend a modelling framework for 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 decision 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 for the 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 and 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, its 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, thus 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.

In addition to literature review, as mentioned above, the Thesis comprises six interrelated scientific publications outlining the main GHG reduction problems in the agriculture sector (Table 1).

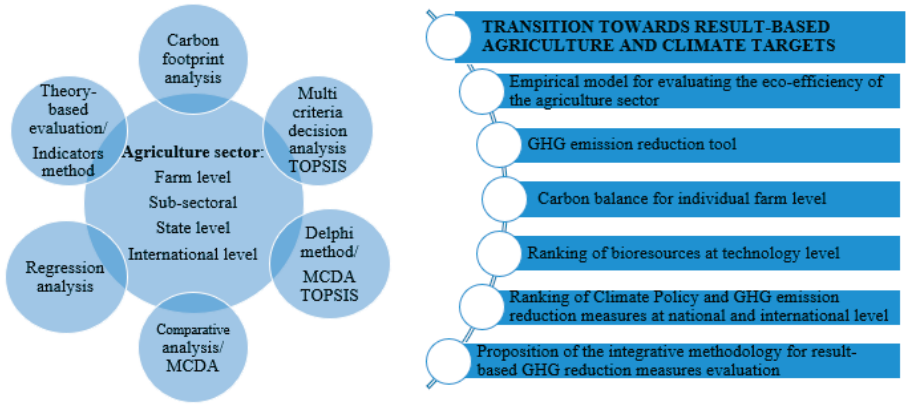

Fig.1. Research structure

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 eco-efficiency 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. Proposition of the decision-making analysis tool	State Sub sectoral
Comparative analysis /MCDA TOPSIS method	6	Towards climate neutrality via sustainable agriculture in soil management		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 method, (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 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, https://content.sciendo.com.

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.
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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

As agriculture sector is the second most significant source of Latvia's GHG emissions, with 19.8 % of total GHG emissions excluding land use, land-use change and forestry (LULUCF) in 2019, the Thesis is more focused on this part of emissions. In 2019, the largest part of the total agriculture sector emissions (given in kt CO_2 eq.) constitutes N_2O emissions (54.6 %), then follow CH_4 (42.9 %), and only 2.5 % is CO_2 emissions from liming and urea application [1]. Sectors included in the GHG inventory interact with each other. 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 are planned to be merged after 2030.

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. Based on the 2021 Report on Policies, measures and GHG projections submitted to the EC [4] 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. 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.1.1).

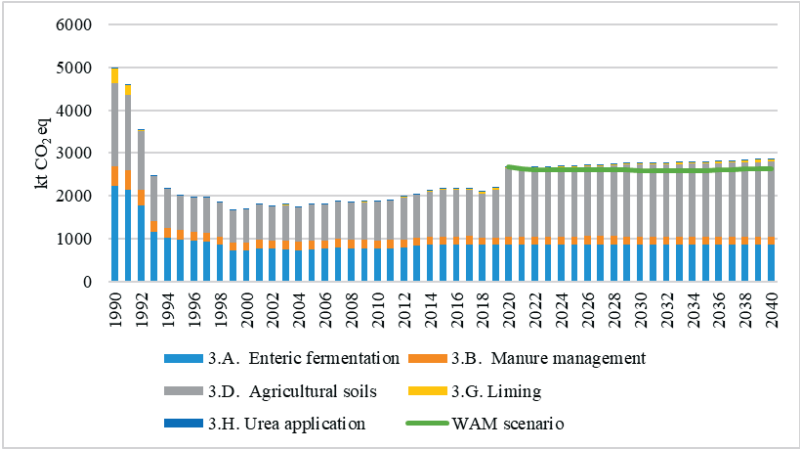

Fig. 1.1. Latvia's historical and projected agriculture emissions by source category [5]

As it can be seen in Fig. 1.1, despite many policies and measures (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 allows the conclusion that there are GHG mitigation measures in place in Latvia, but the measures of specific result indicators are not set, thus hampering the full success of climate change mitigation. Comprehensive work on a state scale result-based indicator system establishment for agriculture sector could optimize trends and stimulate sustainable approaches. According to the report [6], the existing PAMs are related to the implementation of the Nitrate Directive, renewable energy sources directive, and CAP. 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

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. emphasize three essential elements of result-based approaches [7]: 1) choosing measurable results; 2) establishment of a payment and verification mechanism; and 3) 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 [8]. According to the result-based approach [9], newly introduced and emphasized

by EU`s communication on Sustainable Carbon Cycles [4] and related documents [10–11], 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. Thinking more broadly, the concept of the result-based agriculture sector is related to sustainability and smart agriculture principles, therefore, it is very 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. Examples of environmental, climate and economic performance measurement indicators, which were mentioned in the literature, are summarized in Table 1.1 [12].

Table 1.1

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 • 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 to 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

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

In the Thesis, four main steps were considered, which in general characterize the process of eco-efficiency performance implementation (Fig. 2.1). Regression analysis was used for the evaluation of relationship between the GHG emissions and production of agricultural products and other parameters.

Fig. 2.1. Eco-efficiency performance process

In order to assess the eco-efficiency of the agriculture sector, first of all, the necessary statistical data were studied and collected. The selection of indicators depends on the ways they will be used. Based on the literature analysis, the following indicators were selected for evaluation: 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 1.1); but for detailed eco-efficiency analysis: 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. The regression analysis is used to identify the strength of effect that the independent variable has on a dependent variable. As economic indicator the gross domestic product (GDP) of the sector, and for measuring of the environmental indicators – emissions were used.

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 basic methodological framework concept is shown in Fig. 2.2. 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 the 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 were used. In order to achieve the second goal of the dissertation, an analysis of existing indicators was carried out based on the

literature review to provide a tool for assessing the GHG emission reductions and to help stakeholders make decisions on the sustainability of the agriculture sector, including the production of high value-added agricultural products.

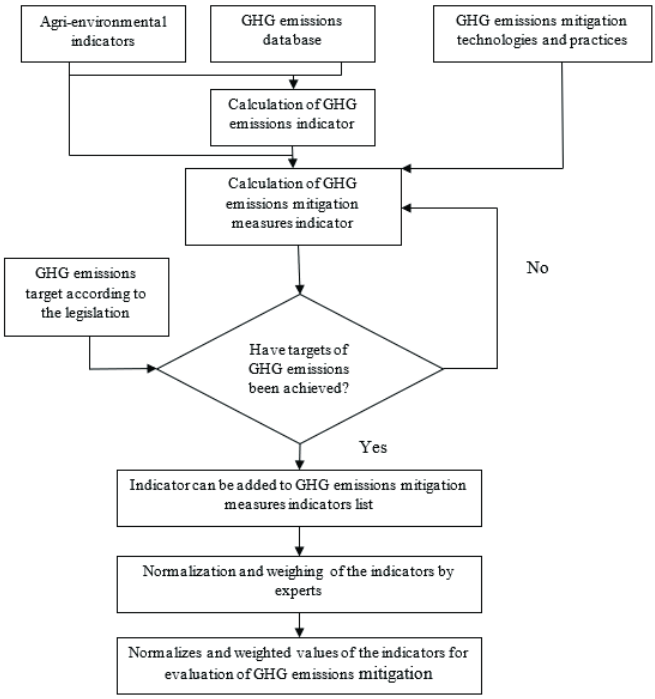

Fig. 2.2. Methodological framework of selection and evaluation of indicators for GHG mitigation measures in the agriculture sector

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. 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. To calculate the total fuel consumption for maize for biogas production, first, data on the use of off-road fuel for a specific type of tillage (tonnes per hectare) were collected. 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

N_2O emissions during maize cultivation also result from the incorporation of crop residues, nitrogen fertilizers, and digestate into the soil. N_2O emissions from managed soils were calculated using the Tier 1 methodology according to the 2006 IPCC guidelines, including default emission factors [13], [14]. For direct N_2O emissions calculation from agricultural soils management, Equation 2.1 was used:

$$N_2O - N = [(F_{SN} + F_{CR}) \times EF], \quad (2.1)$$

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 2.2 was used to convert kg N_2O–N emissions to N_2O emissions:

$$N_2O = N_2O - N \times 44 \times 28. \quad (2.2)$$

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 standards [15] were used, which state 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. 2.3) according to the Tier 1 methodology of the 2006 IPCC guidelines:

$$F_{CR} = Yield \times DRY \times Frac_{Renew} \times Area \times R_{AG} \times N_{AG} \times Area \times R_{BG} \times N_{BG}, \quad (2.3.)$$

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 $R_{BG\text{-}BIO}$ 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) [16].

To calculate the annual production of crop residues F_{CR}, the following calculation (Eq. 2.4) is required:

$$R_{AG} = \frac{AG_{DM} \times 1000}{Crop}, \quad (2.4)$$

as well as additional equation (Eq. 2.5) to estimate terrestrial surface solids AG_{DM} (Mg ha^{-1}) [10]:

$$AG_{DM} = \left(\frac{Crop}{1000}\right) \times slope + intercept. \quad (2.5)$$

And the correction factor for estimating the dry matter yield is determined as in Equation 2.6:

$$Crop = Yield_{Fresh} \times DRY, \quad (2.6)$$

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)$^{-1}$ [13].

2.4. Multi-criteria decision analysis

Multi-criteria analysis [17] 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 [18]–[19].

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 [20].

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 %.

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 decision analysis TOPSIS method is used as a methodological concept to achieve the objectives of Tasks 5 and 6, as it makes it easy to compare different alternatives [21]. The approach used for the evaluation is shown in Fig. 2.3.

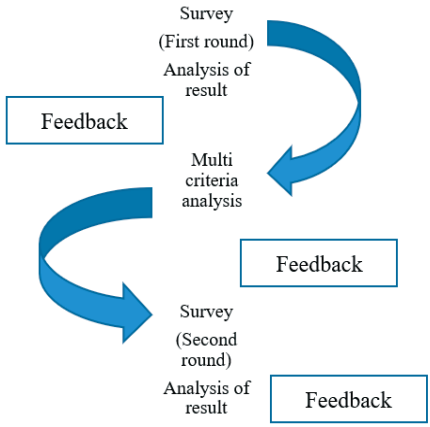

Fig. 2.3. Scheme of the used Delphi technique and TOPSIS for analysis

The Delphi approach was used to get expert opinions regarding existing and planned policies and measures for GHG emission reductions in the agriculture sector. Experts were selected according to their competence. Nineteen GHG reduction measures for WEM and WAM scenarios were included in the survey. These measures were taken from Latvia's fourth biennial report (BR4) [22] submitted to the UNFCCC and from the National Energy and Climate Plan (NECP) of Latvia [2]. Each expert was asked to assess the nineteen mitigation measures from an economic, engineering-technical, environmental/climate and social aspect.

The initial input 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. The experts were asked to prepare their own opinion/prediction. All participants remained anonymous. 18 experts answered questionnaires in two rounds. The experts provided answers and additional descriptions and judgments.

Between these two rounds of the survey, a MCDA was performed (Fig. 2.3), which allowed for the prioritization and assessment of different measures from the economic, technical, environment/climate and social perspective. Additionally, experts were asked to consider the replies of the first round and the answers of other experts in order to get an overview/opinion regarding the most appropriate measures for GHG reduction in future for moving to smart agriculture, where the efficient use of resources is one of the main goals.

2.6. Combination of comparative and multi-criteria decision analysis

The Thesis used a combination of comparative analysis and MCDA, TOPSIS method 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. The study has been developed in two parts.

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.

In the second part of the study, the literature review was first carried out [23]–[25]. 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. Once the assessments were obtained, an MCDA was performed using the TOPSIS method. To determine the best alternative from each product group, MCDA was initially performed for each 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 best alternative.

Participants for the survey/questionnaire were selected based on their experience and knowledge. The questionnaire was sent to 20 sectoral experts, and responses were received from all respondents. In the questionnaire, 25-grain products were selected and divided into three groups – food products, pharmaceutical products, and products used for transport, and 7 straw products 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, and biohydrogen. The selected straw products were: litter in barns, pellets, fibers, disposable tableware, drinking straws, reusable tableware, and bioplastic.

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 [26]. Other activity data were taken 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 the amount of fuel used in the sector corresponding with the 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 %; with similar situation in 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. 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.

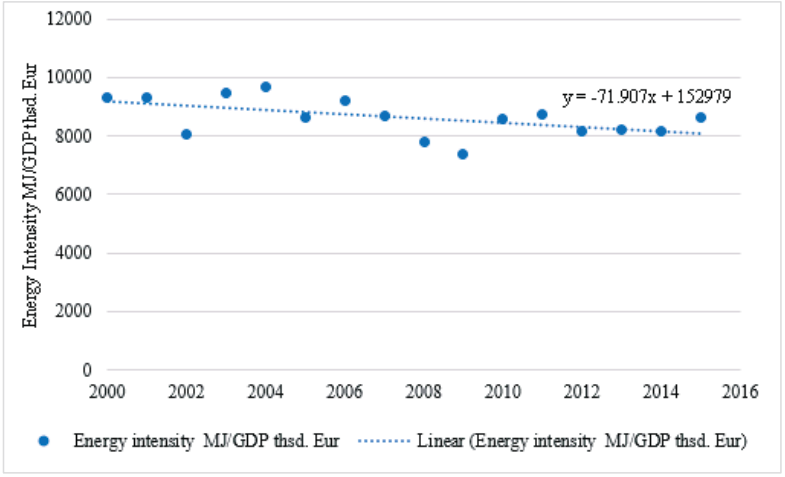

Fig. 3.1. Energy intensity MJ/GDP

Secondly, CH_4 and N_2O emission intensity in the agriculture sector were analysed (Figs. 3.2 and 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, which 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.

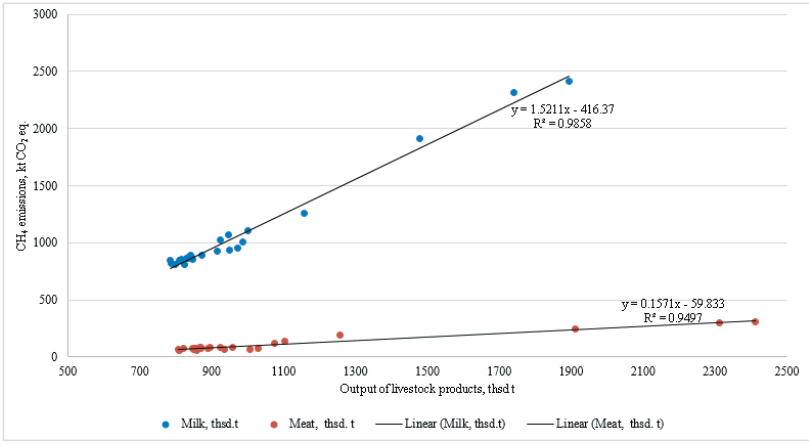

Fig. 3.2. Link between CH_4 emissions (kt CO_2 eq.) and meat and milk production

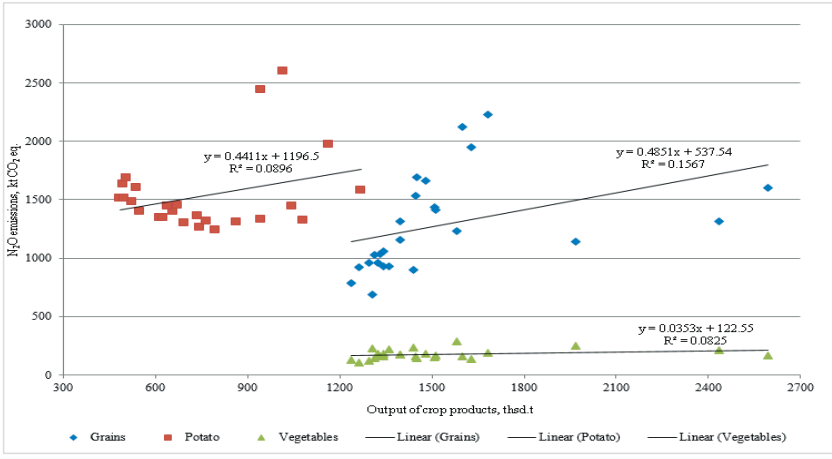

Fig. 3.3. Link between the crop production and N_2O emissions (kt CO_2 eq.)

Overall analysis of the eco-efficiency in the agriculture sector is presented in the 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 been seen in Fig. 3.4, GHG emissions in the agriculture sector (~28 %) and GDP (~48 %) have a 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 N_2O emissions and the 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. Water use data [27] 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.

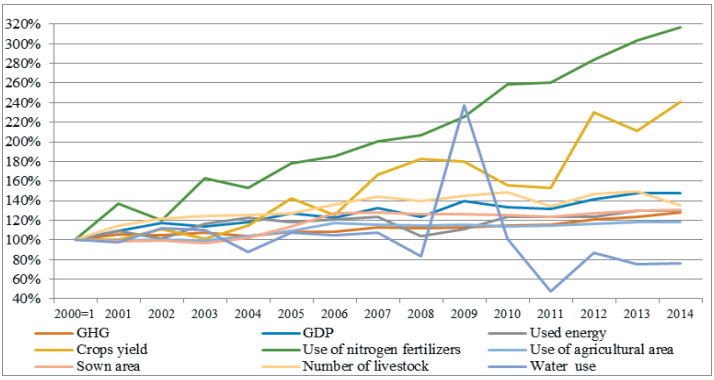

Fig. 3.4. Changes (%) of main indicators in agriculture in 2000–2014 (2000=1)

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.

The EC has developed 35 agri-environmental indicators for assessing impacts of agriculture [28]. 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.

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 3.1

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
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 the production of renewable energy • Decrease the 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.

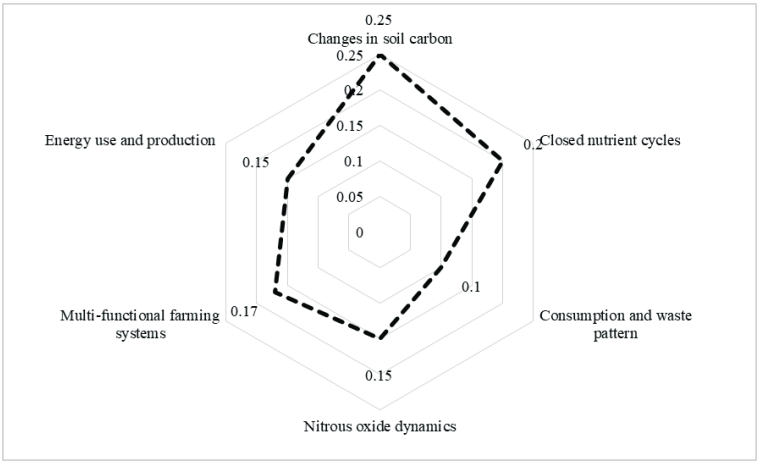

Fig. 3.5. Decision-making matrix

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. Table 3.2 shows the CO_2 eq. emission indicators per 1 ha of biogas produced from specially cultivated maize.

Table 3.2

Fuel Emission Indicators per 1 ha of Cultivated Maize Area [10]

	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_2 eq. 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 3.3.

Table 3.3

Total Indicative Emissions of Biogas Production from Grown Maize in 2017, per ha [10]

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

The study concludes that despite diesel consumption and emissions from the maize production process, maize absorbs much more carbon than it produces and can save 1.86 kg CO_2 eq. per 1 m^3 of biogas produced (normal pressure, 760 mm Hg).

3.4. Ranking of bioresources 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. 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. To obtain the cost of producing 1 m^3 of biogas from a given substrate, the substrate price was divided by the substrate efficiency.

As a result, the three main criteria identified as determinants of biogas substrate selection were summarized in Table 3.4 for comparison.

Table 3.4

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

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.

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 the criteria. The last places are organic waste, maize silage, and wood.

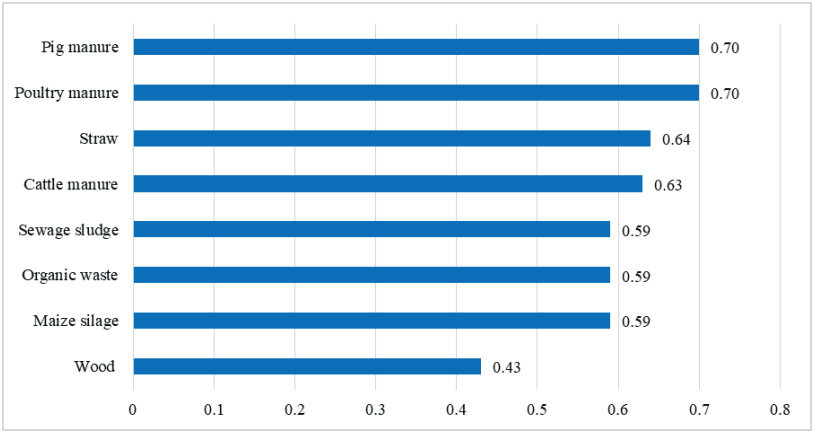

Fig. 3.6. Relative closeness to the ideal solution with TOPSIS method for substrate ranking

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

The Thesis introduces a method that could be used in addition to the 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 the 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 Fig. 3.7.

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 use of 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.

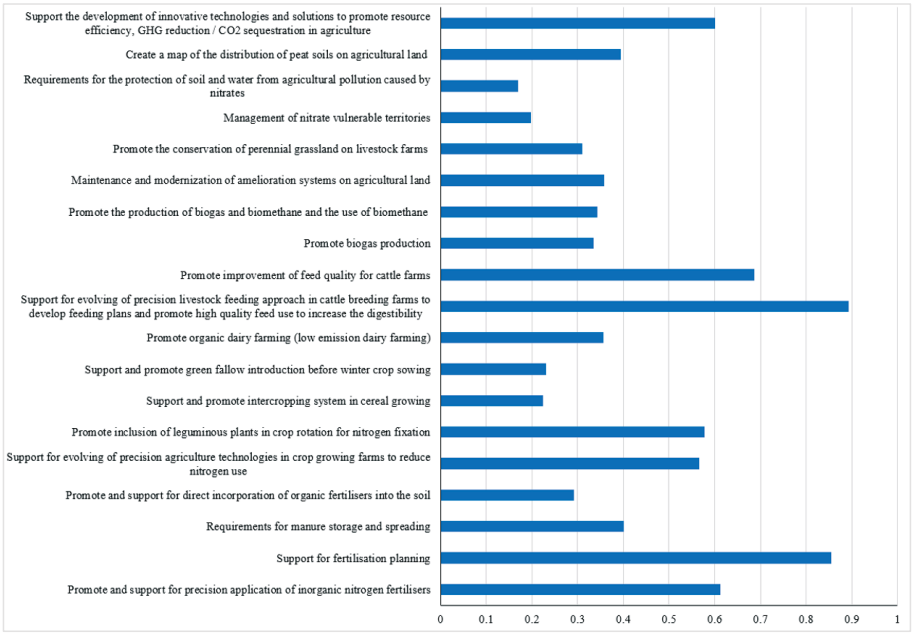

Fig. 3.7. Ranking of measures by TOPSIS

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.

Table 3.6

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	
Weak (0–0.2)	Management of nitrate vulnerable territories	Water and soil protection requirements from pollution related nitrates			

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 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 towards 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 towards 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 3.7).

Table 3.7

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 weaknesses 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 results, 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, and science-based is shown in Fig. 3.8. 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.

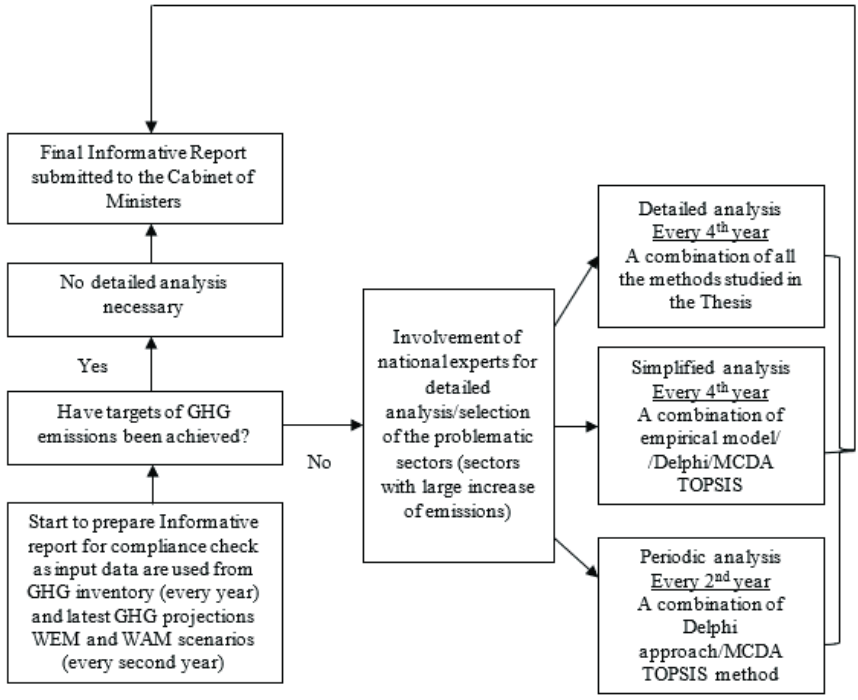

Fig. 3.8. National-level process proposed for the self-assessment of compliance with GHG emission reduction commitments

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:

- Agriculture sector is related to other sectors in GHG inventory, for example, the 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.

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