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TRANSITION TOWARDS RESULT-BASED AGRICULTURE SECTOR AND CLIMATE TARGETS

Summary of the Doctoral Thesis

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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		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	5382	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:

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

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:

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

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.

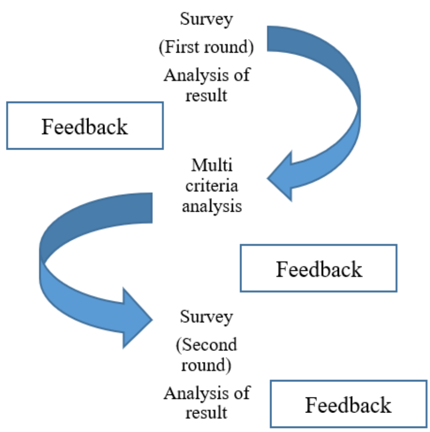

Fig. 2.3. Scheme of the used Delphi technique and TOPSIS for analysis

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.

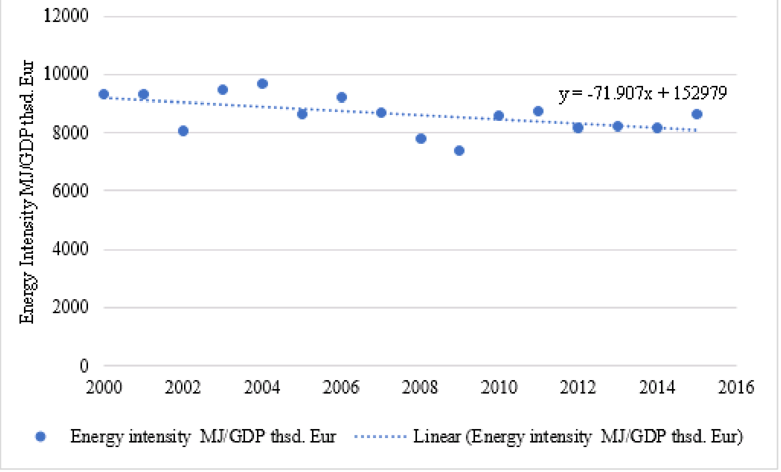

Fig. 3.1. Energy intensity MJ/GDP

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.

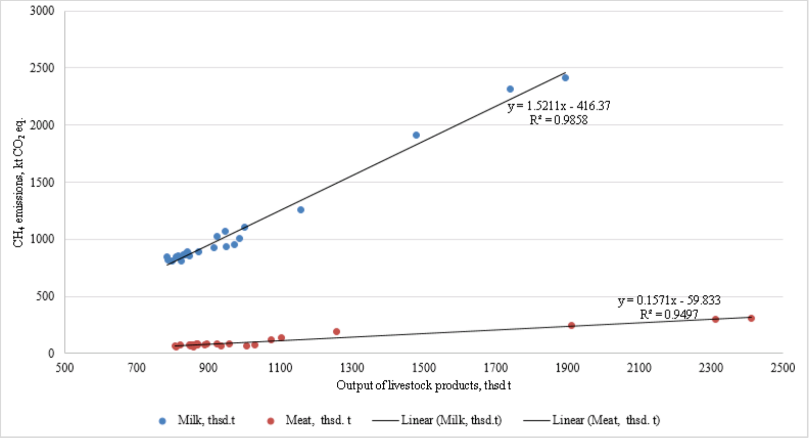

Fig. 3.2. Link between CH_4 emissions (kt CO_2 eq.) and meat and milk production

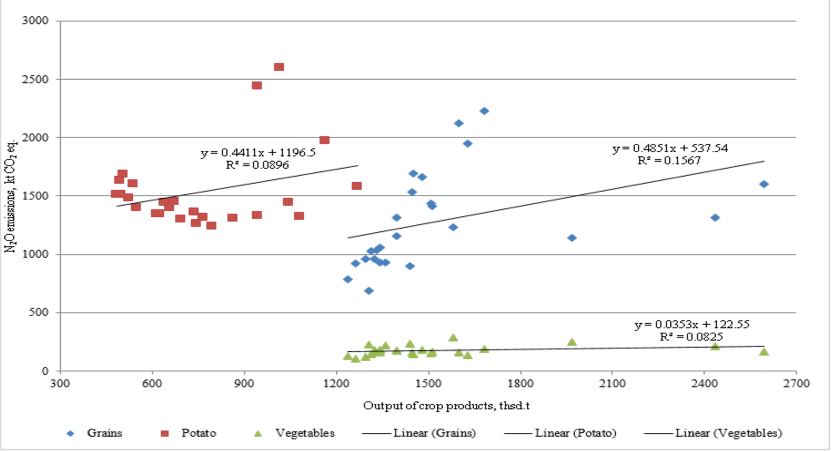

Fig. 3.3. Link between the crop production and N_2O emissions (kt CO_2 eq.)

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.

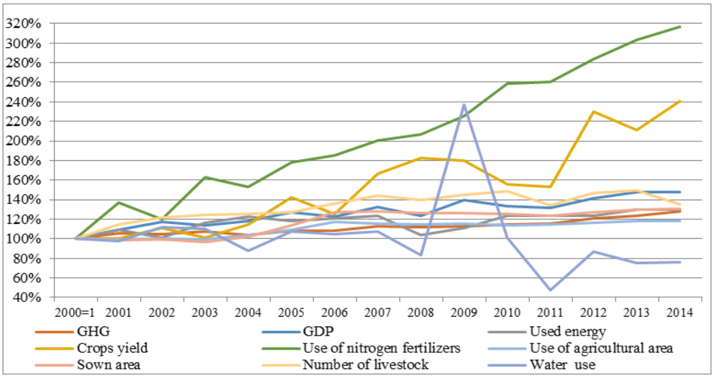

Fig. 3.4. Changes (%) of main indicators in agriculture in 2000–2014 (2000=1)

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.

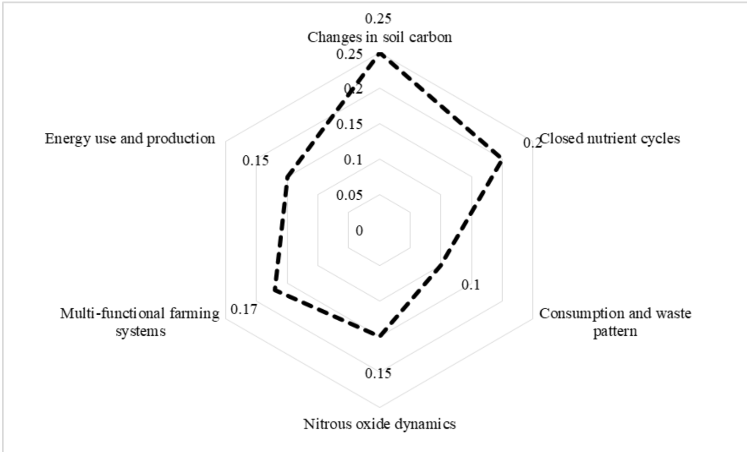

Fig. 3.5. Decision-making matrix

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.

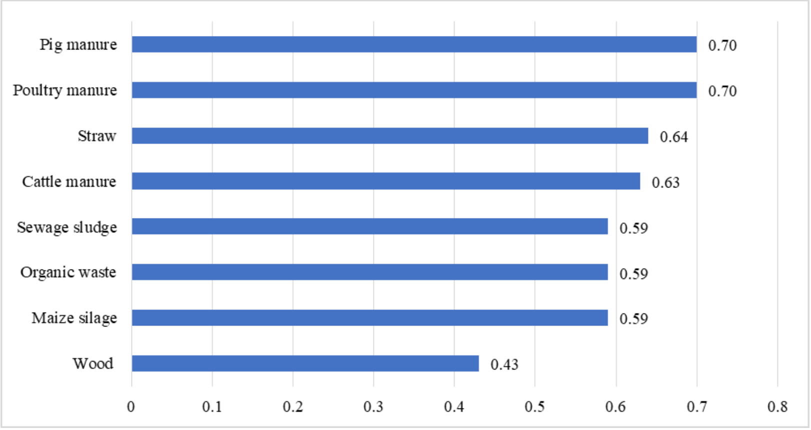

Fig. 3.6. Relative closeness to the ideal solution with TOPSIS method for substrate ranking

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.

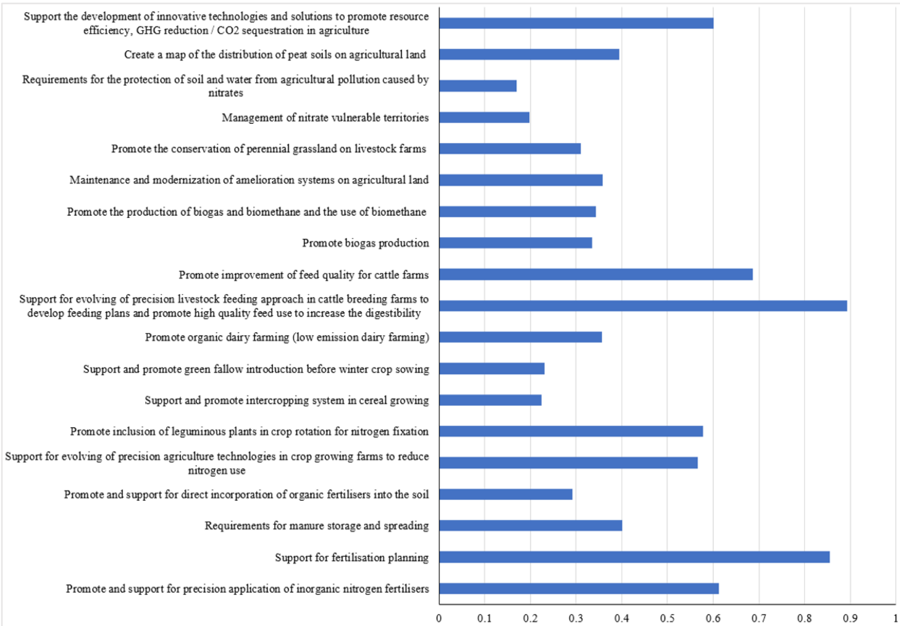

Fig. 3.7. Ranking of measures by TOPSIS

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.

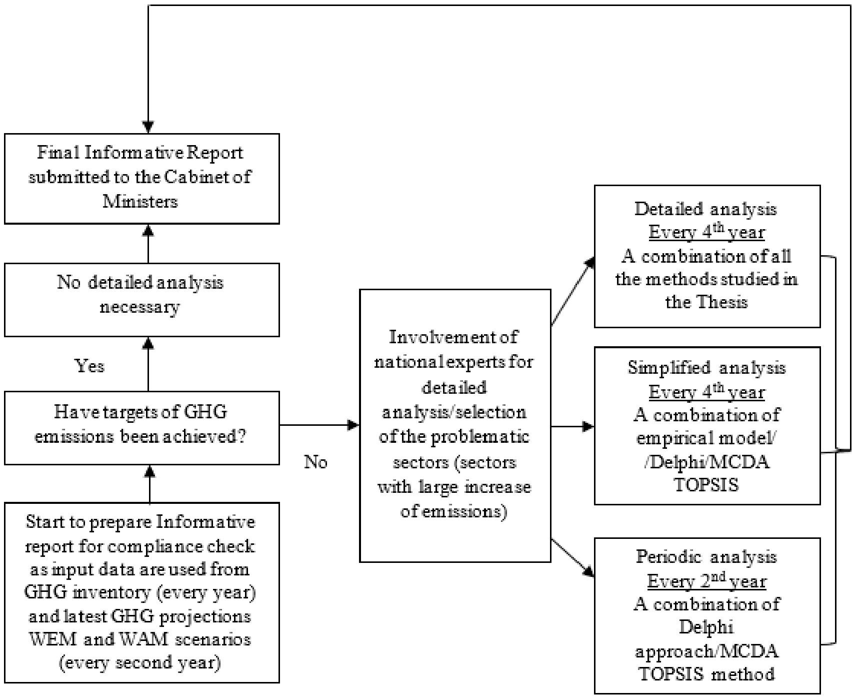

Fig. 3.8. National-level process proposed for the self-assessment of compliance with GHG emission reduction commitments

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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