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CARBON FARMING TOWARDS CLIMATE NEUTRALITY

Doctoral Thesis

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ANOTĀCIJA

Eiropa jau 20. Gadsimtā ir piedzīvojusi vidējās gaisa temperatūras paaugstināšanos par 0.8°C, un simulācijas liecina, ka nākotnē sagaidāmais temperatūras paaugstināšanās temps desmitgadē būs no 0.1 līdz 0.4°C, ko izraisīs antropogēnās siltumnīcefekta gāzes. 2015.gada 12. Decembrī UNFCCC puses ratificēja Parīzes nolīgumu un ir apņēmušās līdz 2030.gadam samazināt emisijas par vismaz 55% salīdzinājumā ar 1990.gada līmeni un līdz 2050.gadam būt klimat-neitrālām. Lauksaimniecības nozare ir 3. lielākā SEG emisiju nozare Latvijā, kā arī Eiropā, un tā kā tā ir tiešā un netiešā veidā saistīta ar visām citām nozarēm, tostarp enerģētikas un transporta nozari, tās dekarbonizācijai var būt ne tikai vides, bet arī ekonomiska un sociāla ietekme. Pārveides virzienu ietekmē dažādas stratēģijas, tomēr katrai dalībvalstij šīs stratēģijas ir jāizstrādā individuāli, un nepārdomāti pieņemta politika, kas orientēta tikai uz konkrētām lauksaimniecības apakš-nozarēm vai uzņēmumu grupām, neskatot sektoru un tā specifiku kopumā, var ne tikai novērst šo mērķu sasniegšanu, bet pat to aizkavēt. Tāpēc šī pētījuma mērķis ir analizēt lauksaimniecības sektora esošo situāciju un definēt priekšnosacījumus sektora attīstībai ceļā uz oglekļsaistīgu un ilgtspējīgu lauksaimniecību. Lauksaimniecības sektora analīzei tika izmantotas vairākas metodes – oglekļa bilances metode, ilgtspējības SVID analīze, daudz-kritēriju analīze, TIMES un sistēmdinamika.

Pētījumā tika konstatēts, ka, neņemot vērā ētiskos aspektus biogāzes ražošanas procesā, biogāzes ražošana no speciāli audzētas kukurūzas līdz šim lauksaimniecībā nav radījušas kaitējumu videi emisiju kontekstā, jo, lai gan tiek izmantoti fosilie resursi, šāda biogāzes ražošana spēj ietaupīt 1.86 kgCO_2eq emisijas uz 1 m^3 saražotās biogāzes. Tas gan nav salīdzināms ar potenciāli iespējamajiem ietaupījumiem tikai no atlikum-produktiem, piemēram, cūku un citu lauksaimniecības dzīvnieku kūtsmēsliem un augu atliekām, citiem bioloģiskajiem atkritumiem. Gan ētisku, gan ekonomisku pretrunu, gan likuma nestabilitāte biogāzes sektoru Latvijā ir ietekmējusi negatīvi un šobrīd jāsaskaras ar daudziem ne tikai tehniskiem un ekonomiskiem izaicinājumiem, bet arī sabiedrības skepsi, kas kavē šī sektora attīstību, taču, ņemot vērā šī sektora stiprās puses, Latvijā biogāzes ražošanai ir vēl neizmantots potenciāls. Lai sektors varētu darboties neatkarīgi no subsīdijām, svarīgi palielināt pievienoto vērtību, ko varētu panākt ar biogāzes attīrīšanu biometānā, kam savukārt ir 3 reizes lielāks potenciāls izmantojot biometānu transporta sektorā, nekā biogāzes sadedzināšana koģenerācijas stacijās, izmantojot tādā veidā saražoto siltumu un elektrību. Lai to sasniegtu, ir kritiski nepieciešami jauni motivācijas instrumenti, kas mudinātu attīstīt visu lauksaimniecību kopumā ilgtspējas virzienā, tātad attīstot arī bioekonomiku un resursu efektīvu saimniekošanu, kas padarītu jaunās tehnoloģijas un lauksaimniecību kopumā ekonomiski stabilāku, neatkarīgāku, ilgtspējīgāku un konkurētspējīgāku globālajā tirgū. Ir pamatoti lielas cerības, ka nākotnē šo motivāciju sniegs Eiropas Savienības Oglekļsaistīgas lauksaimniecības (Carbon Farming) iniciatīva, kurā lauksaimnieki tiks atalgoti par oglekļa dioksīda savākšanu no atmosfēras un noglabāšanu, ko potenciāli būs iespējams paveikt ar dažādām metodēm. Šobrīd tiek izstrādāti risinājumi, tāpēc šajā pētījumā tika apkopotas daži pēc autora domām Latvijai piemērotākie oglekļsaistīgas lauksaimniecības risinājumi, un tika noskaidrots, ka Latvijas apstākļiem lielākais potenciāls varētu būt oglekļa noglabāšana augsnē, biometāna ražošana un ilggadīgo augu stādīšana. Šis pētījums vēlreiz pierāda biogāzes sektora nepieciešamību attīstīties, taču, ņemot vērā, ka no kopējām emisijām lauka augkopība atbild tikai par aptuveni pusi emitētā apjoma (neskaitot ar dīzeļdegvielu radītās emisijas), 45% emisijas tiek radītas lopkopības apakš-sektora dēļ.

Šī disertācija ir pierādījums tam, cik kritiski svarīga ir vieda, ilgtspējīga lauksaimniecības pārvaldība, kuras pamatā ir atbildīgo personu rokās pieņemtie likumi. Izmantojot šo darbu un izstrādātos modeļus turpmāko lēmumu pieņemšanā gan uzņēmumu, gan valsts līmenī, būtu iespējams ievērojami celt lauksaimniecības konkurētspēju globālajā tirgū, samazinot tā atkarību nākotnē no valsts subsīdijām, vienlaikus ievērojami mazinot tā ietekmi uz vidi un samazinot klimata pārmaiņas.

ANNOTATION

Europe has already experienced an average surface air temperature rise of 0.8 °C during the 20th century, and simulations show that the future expected rate of temperature rise per decade will be between 0.1 and 0.4 °C caused by anthropogenic greenhouse gases. On 12th December 2015, Parties to the UNFCCC ratified the Paris Agreement and have committed to reducing emissions by at least 55 % by 2030 compared to 1990 levels and being climate-neutral by 2050. Agriculture sector is the 3rd biggest GHG emission sector both in Latvia and Europe and as it is directly and indirectly linked to all other sectors, including energy and transport sector, it's decarbonization can have not only environmental, but also economic and social impact. The direction of the transformation is influenced by different strategies; however, every member state has to develop these strategies individually, and thoughtlessly adopted policies that focus only on specific agricultural sub-sectors or groups of companies, may not only prevent these goals, but may even delay them. Therefore, the purpose of this research is to analyze the current situation of the agricultural sector and define the prerequisites for the development of the sector on the way towards carbon-restricted and sustainable agriculture. Several methods were used for the analysis of the agricultural sector – carbon balance method, sustainability SWOT analysis, multi-criteria analysis, TIMES and System dynamics.

The study revealed that, without considering the ethical aspects in the biogas production process, biogas production from specially grown maize has not caused environmental damage in terms of emissions so far in agriculture, because although fossil resources are used, such biogas production is able to save 1.86 $kgCO_2eq$ emissions per 1 m^3 of biogas produced. However, this is not comparable to the potentially possible savings only from residual products, such as manure, plant residues and other biological waste. Both ethical and economic contradictions, as well as the instability of the law have negatively affected the biogas sector in Latvia, and currently we must face many not only technical and economic challenges, but also public skepticism, which hinders the development of this sector, however considering the strengths of this sector, biogas production in Latvia has an untapped potential. For the sector to function independently of subsidies, it is important to increase the added value that could be achieved by purifying biogas into biomethane, which in turn has 3 times bigger potential in transport sector than burning biogas in cogeneration plants using the heat and electricity. To achieve this, new motivational tools are critically needed, which would encourage the development of all agriculture in general in the direction of sustainability, thus also developing the bioeconomy and efficient management of resources, which would make new technologies and agriculture in general more economically stable, independent, sustainable, and competitive in the global market. There are justifiably high hopes that in this motivation will be provided by the European Union's Carbon Farming initiative, in which farmers will be rewarded for collecting carbon dioxide from the atmosphere and storing it, which can potentially be done by various methods. Unfortunately, this idea is still in the development stage, so it is not completely clear, how it will be achieved and which methods are the best for particular cases, so in this study, some of the most appropriate carbon farming solutions for Latvia were collected (collection based on author's subjective opinion after an extensive literature review) and it was clarified that the greatest potential for Latvian conditions could be carbon storage in the soil, biomethane production and planting perennials. This study once again proves the need for the development of the biogas sector, but considering that out of the total emissions, field crop production is responsible for only about half of the emitted volume of emissions (emissions generated by diesel fuel are not included in the statistics), 45 % of the emissions are caused by the livestock sub-sector.

This Thesis is a proof of the critical importance of smart, sustainable agricultural management, which is so dependent on individuals that makes the law, strategies, and other important decisions. Using this work and the developed models in future decision-making, both at the company and national level, it would be possible to significantly increase the competitiveness of agriculture in the global market, reducing its future dependence on state subsidies, while significantly reducing its impact on the environment and climate change.

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I wish everyone such a strong support team that makes every dream possible!

TABLE OF CONTENTS

ABBREVIATIONS

BECCS	Bioenergy with Carbon Capture and Storage
CAP	Common Agriculture Policy
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CDR	Carbon Dioxide Removal
CF	Carbon Farming
CHP	Combined Heat and Power
DAC	Direct Air Capture
DACCS	Direct air carbon dioxide capture and storage
DC	Degradable Organic Component
DNA	Deoxyribonucleic Acid
EC	European Commission
EEM	Energy Efficiency Management
ETS	Emissions Trading System
EU	European Union
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LTESL2030	Latvian Energy Long-term Strategy 2030
MPC	Mandatory Procurement Component
NECP	National Energy and Climate Plan
NIP	National Industrial Policy
SDSL2030	Latvia's Sustainable Development Strategy for 2030
SSPs	Shared Socioeconomic Pathways
TOPSIS	The Technique for Order of Preference by Similarity to Ideal Solution
UNFCCC	The United Nations Framework Convention on Climate Change
USA	United States of America
USSR	Union of Soviet Socialist Republics
VAT	A Value Added Tax

INTRODUCTION

The Relevance of the Topic

Europe has already experienced an average surface air temperature rise of 0.8 °C during the 20th century [1], and simulations show that the future expected rate of temperature rise per decade will be between 0.1 and 0.4 °C [2], caused by anthropogenic greenhouse gases (GHG) [3]. The global mean temperature in 2021 was already about 1.1 °C above the 1850 – 1900 average temperature [4]. On 12th December 2015, Parties to the UNFCCC ratified the Paris Agreement and have committed to reducing emissions by at least 55 % by 2030 compared to 1990 levels and being climate-neutral by 2050 [5].

The energy sector is responsible for 64.0 % of the total GHG emissions in Latvia in 2016, of which the transport sector is responsible for 44.2 %, while the agricultural sector is responsible for 23.6 % of the total Latvian GHG [6]. Agriculture is in the most direct contact with natural resources - water, land, plants, animals, natural minerals, energy - and is directly and indirectly linked to all other sectors, including energy and transport sector [7]. Not only its connection with other sectors, all kinds of resources, but also the diversity of its activity makes it a very complex, difficult sector to organize, but it is a very important investment both in terms of environmental and also in economic development [8],[9]. The direction of the transformation is influenced by different strategies. Climate Neutrality Strategy 2050 measures to achieve the goal planned in the strategy are to achieve resource-efficient agriculture that produces products with high added value and high productivity, and to increase agricultural investment in bioenergy, for example, biogas production [10]. Efficient management of agricultural sector and use of biogas could have a positive effect on reducing emissions from not only agricultural sector, but the development of biogas production alone will also not allow to decarbonize the entire agricultural sector. That's why the EU aims to find new ways to decrease GHG emissions through a new approach for Europe—the EU Carbon Farming initiative—stating that farming practices that remove CO_2 from the atmosphere should be rewarded in line with the development of new EU business models [11]. However, European Commission acknowledges that carbon farming is in its infancy and there is a lot to be addressed, and it is crucial and challenging to implement energy efficiency and resource efficiency measures without simultaneously reducing productivity [12], because one of the main challenges facing the agricultural industry is to provide food for the increasing population while reducing its influence on the climate and environment.

Inclusive, sustainable, growth-promoting and equitable development of all sub-sectors of agriculture could not only have a large impact on an agricultural sector itself, but also other sectors in which it is necessary to reduce GHG emissions [13],[14]. However, unprofessionally adopted policies that focus only on specific agricultural sub-sectors or groups of companies, may not only prevent these goals, but may even delay them. It should be taken into account that agriculture is a very complex system in which simple saving measures and knowledge are not enough to achieve both these savings and productivity [15].

The proposed theses

The following theses were proposed in the work:

- Resource management is an essential prerequisite, which would make it possible to sustainably ensure the progress of the agricultural sector towards climate neutrality;
- The efficiency of resources is an essential prerequisite, with which it would be possible to sustainably ensure the progress of the agricultural sector towards climate neutrality;
- Carbon farming is an essential prerequisite, which would make it possible to sustainably ensure the agricultural sector moves towards climate neutrality;
- The production of products with higher added value is an important factor in the agricultural sector's progress towards climate neutrality, in order to maintain the economic sustainability of companies and the industry;
- Biogas has great potential in Latvia and in the movement towards climate neutrality of the agricultural sector.

The Aim of the Research

The purpose of this research is to examine the impact of climate neutrality measures on the agricultural sector and to define the main prerequisites for the development of the sector on the way towards carbon-restricted, sustainable and viable agriculture. To achieve the goal, the following tasks have been set:

- To analyze the biogas sector and propose the most sustainable solutions;
- To research and clarify the best carbon farming methods for the case of Latvia, where the main emphasis is on the sub-sector of field crop cultivation;
- To study the management of energy efficiency and resource efficiency and determine the importance of their implementation in agricultural enterprises;
- To study how to increase the economic contribution to the agricultural sector by producing products with higher added value from livestock residual products;
- To conduct a case study to assess the importance of the introduction of innovations in the second largest sub-sector of agriculture – animal husbandry.

The Novelty of the Research

The novelty of the research is the cross-cutting analysis for the transition to climate neutral agriculture and implementation of resource management, energy efficiency and carbon farming on two different, but interrelated levels: state (first level) and farm (second level), including a comprehensive emphasis on the agriculture sector.

The first level of the novelty is related to the level of the agricultural sector of Latvia and developed:

- Testing the scientific idea of carbon farming using the multicriteria analysis method;
- Determination of biogas potential with SWOT analysis of sustainability;
- The TIMES model was developed to evaluate the production of products with a higher added value from residual livestock products;
- Use of sustainable biogas in the energy sector using multicriteria analysis.

The second level is related to the analysis, modeling, simulation and forecasting of the operations of companies in various sub-sectors of the agricultural sector, using traditional and non-traditional methods and models.

To develop an integrative decision-making methodology for the transition of agriculture sector to a climate neutrality, a different distribution of research methos, 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. The following methods were used and models were created:

1. Carbon balance to assess the sustainability of biogas raw materials;
2. Sustainability SWOT analysis to assess the current situation and future perspective of the biogas sector;
3. Multi-criteria analysis to evaluate the most suitable raw materials for biogas production in Latvian conditions, the sustainable way of using biogas in the energy sector, as well as the most suitable carbon farming methods for local companies;
4. Energy efficiency analysis to assess the importance of energy and resource management and implementation opportunities in any agricultural enterprise;
5. The TIMES model to assess the production of products with higher added value from residual products in the livestock sector.

Hypothesis

Effective movement towards climate neutrality in the agricultural sector is sustainabile and viable, if there is simultaneous:

- Effective use and management of resources;
- Production of products with high added value;
- Principles of Carbon Farming.

Practical Relevance

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 climate neutrality. This work can be used by any agricultural company, in the development of decision making of various state documents, in studies and other learning processes.

Structure of the Research

The Thesis is based on 8 connected scientific publications, mainly paying attention to solutions suitable for Latvia, as well as the development of methods that would help in the development of sustainable policies in the context of the Green Deal. The Thesis is introduced by a literature review, which presents a discussion of the objectives of the Green Deal in the context of agriculture, an analysis of the literature that provides the background knowledge that is critically needed in conducting such research, as well as an outline of the methodologies used, research results and conclusions. Overall, the structure of the work literally corresponds to the path of the agricultural sector to climate neutrality (see Fig. 1).

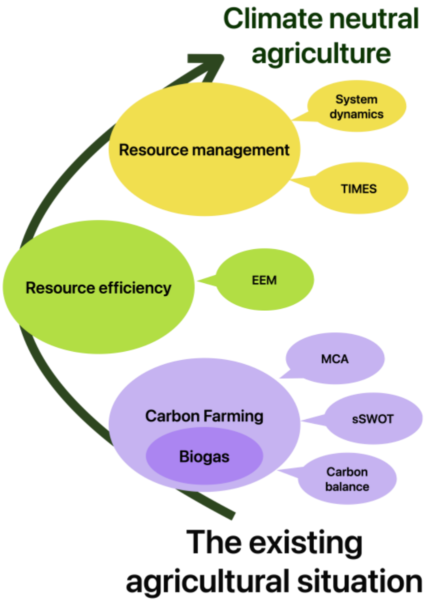


Fig. 1. Structure of the research.

Thesis structure and the role of publications are shown in Table 1.

Table 1.

Thesis structure and the role of publications

Method	Publication number	Publication title	Management level
Carbon balance method	1	Development of a carbon balance methodology for biogas produced from specially grown substrates: A Latvian case study	Farm level
Sustainability SWOT analysis	2	What Will Be the Future of Biogas Sector?	State level Farm level
MCA	3	Ranking of Bioresources for Biogas Production	Farm level
MCA	4	Sustainable biogas application in energy sector	State level Farm level
MCA	5	Development and assessment of carbon farming solutions.	State level Farm level
EEM method	6	The Role of Energy Management in the Agricultural Sector: Key Prerequisites and Impacts.	Farm level
TIMES method	7	Application of TIMES for Bioresource Flow Optimization - Case study of Animal Husbandry in Latvia, Europe	State level Farm level
System dynamics	8	Progress of the agricultural sector towards climate neutrality: identification of essential stages.	Farm level State level

The research is starting from the simplest basic stage, which examines biogas from such different aspects as:

- sustainable production of biogas, where carbon balance was carried out to objectively quantify naturally or anthropogenically added or removed carbon dioxide from the atmosphere to determine the environmental impact of biogas production from specially grown maize silage, which can be used the calculation of its environmental impact for any other substrate too;
- the future of biogas in Latvia, where an understanding of the recent evaluation of the Latvia's biogas sector is provided through the analysis of literature, reports, legislation and scientific articles through a sustainability SWOT analysis;
- bioresources for sustainable biogas production, where multi-criteria analysis was carried out to determine Latvia's biogas sector potential – to predict the best feedstock depending on resources available in the country, which of the substrates for biogas production has the highest potential and sustainability;
- sustainable use of biogas, where multi-criteria analysis was carried out to find out potentially best use for biogas in energy sector.

Although biogas undoubtedly plays an important role in the climate neutrality of agriculture, it will also be an important part of carbon farming policy in the future, so the following research:

- carbon farming, where multi-criteria analysis was done to identify the most suitable carbon farming solutions for Latvian conditions and determine their importance in reducing GHG emissions;

Although carbon sequestration is an important aspect of agriculture's progress towards climate neutrality, it is not possible without economic justification, which leads to the research of:

- energy efficiency, where the aim was to see if there would be a potential energy and emission savings from implementing energy management actions and proposed framework for the energy management system in the agricultural sector on a company level;
- products with higher added value, where the study presents a novel model based on TIMES modelling approach, that helps to investigate the application of new technologies in the agriculture sector and evaluate contribution to agriculture sector in terms of the production of new competitive products, in addition, developing of biorefinery that have a significant impact on both agriculture and other sectors by increasing overall resource efficiency.

To achieve the goal of the Thesis, the final research was done:

- climate neutral agriculture, where a system dynamics model using Latvian dairy farming as a case study was made, so it would not only provide an insight into the system's structure but also identify the system's weak links and allow for the calculations and development of recommendations.

The discussion of the results of the work is presented in a separate (fourth) chapter, where the main statements are highlighted in bold, which highlight the findings made in the doctoral work with the value of future sustainability.

SCIENTIFIC APPROBATION

1. Bumbiere K., Pubule J., Blumberga D. What Will Be the Future of Biogas Sector? Environmental and Climate Technologies, 2021, Vol. 25, No. 1, pp.295-305. Available: https://doi.org/10.2478/rtuect-2021-0021. Published by Sciendo.
2. Bumbiere K., Gancone A., Vasarevičius S., Blumberga D. Ranking of Bioresources for Biogas Production. Environmental and Climate Technologies, 2020, Vol. 24, No. 1, pp.368-377. Available: https://doi.org/10.2478/rtuect-2020-0021. Published by Sciendo.
3. Gancone A., Bumbiere K., Pubule J., Blumberga D. Sustainable biogas application in energy sector. Conference paper. 2020 IEEE 61st Annual International Scientific Conference on Power and Electrical Engineering of Riga Technical University, RTUCON 2020 - Proceedings, 9316593. Available: 10.1109/RTUCON51174.2020.9316593. Published by IEEE.
4. Bumbiere K., Pubule J., Gancone A., Blumberga D. Carbon balance of biogas production from maize in Latvian conditions. Agronomy Research, 2021, Vol. 19, Special issue 1. Available: https://doi.org/10.15159/ar.21.085. Published by EMU DSpace.
5. Bumbiere K., Diaz Sanchez F.A., Pubule J., Blumberga D. Development and assessment of carbon farming solutions. Environmental and Climate Technologies, 2022, Vol. 26, No. 1, pp.898-916. Available: https://doi.org/10.2478/rtuect-2022-0068. Published by Sciendo.
6. Bumbiere K., Sereda S., Pubule J., Blumberga D. The Role of Energy Management in the Agricultural Sector: Key Prerequisites and Impacts. Agronomy Research, 2023, Vol. 21, Special issue 2, pp.439-450. Available: https://doi.org/10.15159/AR.23.034. Published by EMU Dspace.
7. Bumbiere K., Feofilovs M., Asaris P., Blumberga D. Application of TIMES for Bioresource Flow Optimization - Case study of Animal Husbandry in Latvia, Europe. Recycling, 2023, Vol. 8, No. 5, pp.70. Available: https://doi.org/10.3390/recycling8050070. Published by MDPI.
8. Bumbiere K., Meikulane E., Gravelsins A., Pubule J., Blumberga D. Progress of the agricultural sector towards climate neutrality: identification of essential stages. Sustainability, 2023, Vol. 15, No. 14, 11136. Available: https://doi.org/10.3390/su151411136. Published by MDPI.

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

1. Bumbiere K., Pubule J., Blumberga D. What Will Be the Future of Biogas Sector? International Scientific Conference of Environmental and Climate Technologies, CONECT, 2021 May 12 – 14, Riga, Latvia.

2. Bumbiere K., Gancone A., Vasarevičius S., Blumberga D. Ranking of Bioresources for Biogas Production. International Scientific Conference of Environmental and Climate Technologies, CONECT, 2020 May 13 – 15, Riga, Latvia.
3. Bumbiere K., Gancone A., Pubule J., Blumberga D. Sustainable biogas application in energy sector. 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.
4. Bumbiere K., Pubule J., Gancone A., Blumberga D. Development of a carbon balance methodology for biogas produced from specially grown substrates: A Latvian case study. Biosystems Engineering 2021 May 5-6, Tartu, Estonia.
5. Bumbiere K., Diaz Sanchez F.A., Pubule J., Blumberga D. Development and assessment of carbon farming solutions. International Scientific Conference of Environmental and Climate Technologies, CONECT, 2022 May 11 – 13, Riga, Latvia.
6. Bumbiere K., Sereda S., Pubule J., Blumberga D. The Role of Energy Management in the Agricultural Sector: Key Prerequisites and Impacts. 13th International Conference on Biosystems Engineering 2023 May 10-12., Estonia, Tartu.
7. Bumbiere K., Meikulane E., Gravelsins A., Pubule J., Blumberga D. Progress of the agricultural sector towards climate neutrality: identification of essential stages. International Scientific Conference of Environmental and Climate Technologies, CONECT, 2023 May 10 – 12, Riga, Latvia.

Other publications:

1. Bumbiere K., Barisa A., Pubule J., Blumberga D., Gomez-Navarro Tomas. Transition to climate neutrality at University Campus. Case study in Europe, Latvia. Environmental and Climate Technologies, 2022, Vol. 26, No. 1, pp.941-954. Available: https://doi.org/10.2478/rtuect-2022-0071. Published by Sciendo. International Scientific Conference of Environmental and Climate Technologies, CONECT, 2022 May 11 – 13, Riga, Latvia.
2. Vistarte L., Pubule J., Balode L., Kaleja D., Bumbiere K. An Assessment of the Impact of Latvian New Common Agriculture Policy: Transition to Climate Neutrality. Environmental and Climate Technologies, 2023, Vol. 27, No. 1, pp.683-695. Available: https://doi.org/10.2478/rtuect-2023-0050. Published by Sciendo. International Scientific Conference of Environmental and Climate Technologies, CONECT, 2023 May 10 – 12, Riga, Latvia.

1. LITERATURE ANALYSIS

1.1. Introduction

Europe has already experienced an average surface air temperature rise of 0.8 °C during the 20th century [1], and simulations show that the future expected rate of temperature rise per decade will be between 0.1 and 0.4 °C [2], caused by anthropogenic greenhouse gases (GHG) [3]. Although the EU is not the largest emitter of GHG emissions in the world, it is the most progressive global leader on the path to climate change mitigation to achieve a modern, climate-neutral and competitive economy [16],[17], because it is a significant risk and challenge for the European economy, ecosystems, and social systems, hence in all sectors in the future [18],[19],[20]. With the rise above 2 °C compared to 1990 levels, heat extremes to critical tolerance thresholds and natural disasters would happen more often [21]. The global mean temperature in 2021 was already about 1.1 °C above the 1850 – 1900 average temperature [4].

On 12th December 2015, Parties to the UNFCCC ratified the Paris Agreement and have committed to reducing emissions by at least 55 % by 2030 compared to 1990 levels and being climate-neutral by 2050 [5]. On 28th November 2018 The European Commission presented its Long-Term Strategy for 2050 “A Clean Planet for All” for a prosperous, modern competitive and climate-neutral economy by 2050, which aims to establish a vision to the realization of The Paris Agreement [22], using the European Green Deal as one of the key points [23]. Green Deal, which was proposed in 2019, is a roadmap, for how to reach the newly set climate goal for 50 – 55 % emission reduction by 2030 and net-zero emission economy by 2050 [24]. It is a plan to make the European Union’s economy sustainable by turning climate and environmental challenges into opportunities, where there are no greenhouse gas emissions by 2050 [25]. It provides an action plan to move to a clean, circular economy and cut pollution. The action plan to reach this target includes investing in environmentally-friendly technologies, supporting industry to innovate, decarbonizing the energy sector and other activities [25]. To reach the target to cut emissions in the EU, increase renewable energy contribution, member state countries were also required to develop national long-term strategies [26],[27]. Taking into account the outlined long-term development directions, the Latvian National Energy and Climate Plan (NECP) for 2021-2030 has been created, which determines the basic principles, goals and action directions for the Latvia’s energy and climate policy for the next 10 years and Strategy towards Climate-Neutrality 2050 [28]. A medium term policy planning document has also been adopted, which covers all sectors of the economy and sets goals and directions for action to promote economic growth for 2021 – 2027 – the National Industrial Policy Guidelines (NIP) [29]. Although the initial goal was to keep global temperature increase below 2 °C above the pre-industrial level [17], Intergovernmental Panel on Climate Change Special Report “Global Warming of 1.5 °C” reflects the necessity to limit the rise in global temperatures to 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways to strengthen the global response to the threat of climate change, sustainable development and efforts to eradicate poverty [30]. It can be achieved by targeting all necessary actions to reach climate neutrality by 2050 [30].

To reach these targets practically, all scenarios recognize the importance of renewable energy development for the decarbonization of the energy sector. Renewable energy production will increase with a particular focus on solar panels and collectors, also wind energy, however it is clear that it will not be technologically possible due to the storage issues [31]. Given that around 6 million tons of agricultural waste is produced in the world yearly and the pathways and strategic priorities for the transition to a net-zero GHG emission economy, it provides a promising future for the development of biogas production, especially for upgraded biogas to biomethane, which is flexible both in use and storage and because its production from agricultural, industrial waste and sewage sludge protects soil, air and water from the pollution [32],[33]. Although there are various forms of support for biogas producers in Europe and elsewhere in the world [34], the legislation in Latvia is so unstable and various in this area that entrepreneurs are afraid to invest in biogas or treatment plants, therefore, even though the number of stations should increase [35], it decreases every year [36]. Given that, in theory, a biogas plant must be able to operate economically independently, even without public subsidies, in parallel with its main task of reducing emissions, the main challenge is to provide practically valuable material with technological information on how to achieve it with maximum efficiency.

The energy sector is responsible for 64.0 % of the total GHG emissions in Latvia in 2016, of which the transport sector is responsible for 44.2 %, while the agricultural sector is responsible for 23.6 % of the total Latvian GHG [6]. Climate change is included as one of the specific objectives of the current common agricultural policy, promoting the implementation of technical measures for both mitigation and adaptation at the farm level. The agriculture sector keeps an essential role in Latvia's economy. The most significant part of the population lives in rural areas, approximately 84 % of the total area. The agricultural sector is responsible for 28.5 % of Latvia's total non-EU ETS GHG emissions in Latvia [37]. Efficient management and use of biogas could have a positive effect on reducing emissions from both sectors. It could be a solution for sectors that would be problematic to electrify, for example, heavy trucks, tractors and other vehicles and machinery [38]. Decarbonization and gasification of the transport sector is currently the most topical topic for the Latvian policy makers, because Latvia, along with other EU Member States, has to ensure that the share of renewable energy in the final energy consumption in 2030 reaches 14 % (the target for this in 2020 is a 10 % share), but only 4.7 % were achieved in 2018 [39]. However, the development of biogas production alone will not allow to decarbonize the entire agricultural sector, that's why it is so important to look for ways to develop the entire sector towards climate neutrality, including biogas and all other directions of agricultural activity, because although Latvia reduced GHG emissions from agriculture between 1990 and 2018, the latest years and projections show a rising trend [40]. Most significant part of emissions is related to agricultural soils (59.3 %) and enteric fermentation 32.6 % (mainly dairy and beef cattle). The GHG emission trend of recent years shows a gradual and steady increase in GHG emissions; for example, between 2005 and 2018 + 12.5 %, and during the period 2013-2018, emissions increased by 2.12 %. According to Latvia's National Energy and Climate Plan 2021 – 2030, total GHG emissions in the agricultural sector are expected to increase from 2020 to 2030, mainly in the enteric fermentation and agricultural soil categories. To achieve determined targets for Latvia's non-EU ETS sector in 2030 and be on track to reach climate neutrality in 2050, the agriculture sector must contribute to GHG emission mitigation. Improved food security and climate-smart activities will be necessary for the agriculture sector to achieve GHG emission reduction. [37]

Undeniably, the adopted policy has a great influence on the direction of agriculture. Although the goal and meaning of the green course are unified [41], common agricultural policy is developed individually by the member states [42]. The new common agricultural policy envisages making EU agriculture fairer, greener, more results-oriented, as well as guaranteeing stable incomes for farmers and protection against bad harvest years and market price fluctuations [43]. The direction of the transformation is influenced by different strategies.

In addition to Green Deal, there is the Common Agricultural Policy (CAP) that supports farmers and ensures food security in Europe. The CAP of the European Union (EU) involves a collaborative effort between the farming community and the broader society and a partnership between Europe and its farmers. The policy's central aim is to assist farmers, enhance agricultural productivity, ensure a fair income for farmers, work towards achieving climate neutrality in agriculture and promote sustainable management of natural resources. Additionally, the policy seeks to encourage the preservation of rural landscapes and territories and promote employment opportunities in agriculture and related industries. Promoting employment opportunities in the agricultural sector is vital as farmers play a crucial part in the food production chain, even though their income does not reflect that [42]. Given these circumstances, the CAP needs to achieve its objectives of mitigating and reducing climate change's impact and promoting the agricultural sector's transition towards climate neutrality.

Climate Neutrality Strategy 2050 measures to achieve the goal planned in the strategy are to achieve resource-efficient agriculture that produces products with high added value and high productivity, and to increase agricultural investment in bioenergy. The "Farm to Fork" strategy aims to make food systems environmentally friendly (neutral or even positive impact); not only help to mitigate climate change, but also adapt to it; reverse the loss of biodiversity; ensure food security and equity; foster competitiveness; and promote a fair trade [44]. It sets specific targets, such as halving the use of pesticides, reducing fertilizers by at least 20 %, increasing the area of organic farming by 25 %, and reducing antimicrobials used on farm animals by 50 %. Another one is the new Biodiversity Strategy for 2030, which is a comprehensive, systemic, and ambitious long-term plan to protect nature, stop ecosystem degradation, and restore degraded ecosystems [45]. In the light of the Green Deal and its 'Farm to Fork' and 'Biodiversity' strategies, the EU aims to find new ways to decrease GHG emissions through a new approach for Europe—the EU Carbon Farming initiative—stating that farming practices that remove CO_2 from the atmosphere should be rewarded in line with the development of new EU business models. However, European Commission acknowledges that carbon farming is in its infancy and there is a lot to be addressed. The European Commission highlights that carbon farming can be promoted via EU and national policies and private initiatives. In the years towards 2030, result-based carbon farming pilots and, eventually, schemes should be settled by Member States and local governments. Therefore, sustainable, and most realistically suitable solutions for reducing emissions through improved farming practices should be defined for each region.

Furthermore, within the framework of the National Energy and Climate Plan (NECP) for 2030, there is a desire to achieve sustainable land management, sustainable farming of agricultural crops and farm animals, respect for the climate, nature protection, improved economic and social aspects, and to make a significant contribution to bioenergy in the field, all without endangering food security and CO_2 sequestration, as well as following the cascade principle; in order to achieve high productivity through the efficient use of bio-resources (including land resources) [46]. Although field crops are responsible for more than half of agricultural emissions in Latvia, other agricultural sectors such as vegetable growing and animal husbandry—which have the lowest profitability—should not be forgotten, especially because animal husbandry is responsible for the remaining agricultural emissions, which amount to about 45 % [47].

1.2. Biogas production

1.2.1. History, driving trends and challenges

Production of biogas using bioresources of agricultural origin plays an important role in Europe's energy transition to sustainability [16],[48],[49] due to the possibilities to use it for different purposes – transportation fuel, heat and electricity generation [50].

The first research on biogas production in Latvia appeared already during the USSR, while in the early 1980s the first biogas plant was built near a pig farm [51]. Although the development of biogas production has been declining since 1991, already in 2009 58 entrepreneurs received a quota for biogas production with a total installed electrical capacity of almost 54 MW [51]. Consumption of biogas produced in 2017 increased to 80.73 MW (3.9 PJ) since 2014, reaching 25.81 % increase of biogas production. [52]

Meanwhile, in 2018, a total of 18 202 biogas plants with a total capacity of 12.6 GW were in Europe, taking the position of a world leader in biogas production, far ahead the USA, which is in the second place with a total capacity of 2.4 GW [53]. Although biogas production in Europe has developed significantly over the past 20 years, the biogas industry in Latvia has not stood out with stability and resilience, as evidenced by the information provided by the Latvian Biogas Association. Since 2016, when 56 biogas plants were in operation, 7 plants have ceased their operations by 2020, moreover, in 2020 at least 5 more biogas plants were planned to close, mainly due to political instability [51].

In Europe, biogas is mainly produced by anaerobic digestion, followed by combustion in cogeneration plants or purified to biomethane purity level and fed into the natural gas network [53]. In 2014 there were 54 biogas plants operating in Latvia with a total capacity of 54.92 MW (3.1 PJ) and out of those 54 biogas plants, 44 used agricultural waste (82 % of biogas cogeneration plants operating in Latvia in 2014 were based on agricultural raw materials), 7 used municipal waste in landfills, but only 3 used domestic or industrial sewage and residues from food production (industrial waste), and all produced biogas burned in cogeneration plants [54].

This situation has arisen due to energy policy, moreover, support for subsidies has recently fallen not only in Latvia, but also throughout Europe, which explains the slowdown or even regression in the development of this sector. To understand the development so far and how it has come to this, it is necessary to look at the history of the industry.

Although the current biogas production potential is unused in many European Union countries, the growth of the biogas production is limited mainly because of the challenges in profitability, but also due to the uncertainty of political decisions [55]. Biogas production in Latvia was economically supported by a mandatory procurement component (MPC), whose elimination is now at the forefront of the promises of many politicians [56]. It is important to note that MPC's abolition and electricity's trading at stock exchange prices, as encouraged by the Latvian Minister of Economy Ralph Nemiro, would mean the closure or bankruptcy of many biogas plants [57]. The main mistake made in the MPC mechanism was to include natural gas cogeneration in this package from 1998, as a result of which in 2015 60 % of MPC payers' money went to imported natural gas producers, but only 40 % to renewables – biogas, hydro, biomass and wind energy producers, which is an indicator of the choice of a failed system [58].

In order to increase the efficiency of energy production, the so-called "maizification" phenomenon began in the world, including in Latvia, when energy crops began to be grown on a very large scale for the production of biogas [59]. If in the production of biogas from cattle manure the yield of biogas is 35 m^3/t, then in the production of maize, the yield of biogas is 190 m^3/t [60]. Unfortunately it means that fossil fuels were used in heavy machinery, but food products in anaerobic digestion process to produce renewable energy [60].

All these circumstances led to another change in legislation, which provides for significantly stricter conditions for producers of renewable energy, including biogas. At present it is assumed that starting from 2021, new mandatory procurement components come into force, where the total fee for MPC for all electricity users will consist of two parts, one of which is fixed, but the other one depends on the consumed energy [61]. It is also impossible to do without cogeneration plants, because then the price of electricity would rise, and heat would be released into the air. At the same time, as financial support decreases, production conditions have increased:

- the regulations include additional requirements for biogas plants regarding the use of residual products, including manure, which means that biogas plants will have to reduce the use of food products, including maize, in biogas production from 2022;
    - from year 2022 to 2025, residual products / organic waste must make up at least 40 % of the total amount of raw materials consumed;
    - from 2026 to 2029 at least 60 % of the total amount of raw materials consumed;
    - from 2030 at least 80 % [62].
- the regulations include a link between the type of resources used in biogas production in a percentage of total amount of raw materials used and the price of

electricity, which means that if a merchant does not comply with the minimum requirements regarding the composition of raw materials to be used during the year, the regulations of the Cabinet of Ministers provide for the abolition of mandatory procurement rights, but for those who does, the coefficient for the price of produced electricity is applied accordingly [62],[63];

- the regulations define the principles of energy production or the use of useful heat energy, which means that the heat produced in cogeneration plants is used efficiently, including the fact that the total amount of useful heat does not include heat energy that is used for own consumption. If it is possible to produce electricity and useful heat at the same time, the actual total efficiency of energy production is 75 % or more [62],[64].

1.2.2. Biogas production process and characteristics

Literature review in this chapter was conducted to fully understand the importance of raw material selection in biogas production process, looking at each stage of biogas production separately, which relates to the choice of the feedstock. The literature review also looked at the related biogas production steps and processes in general, which allows to understand the whole set of processes and coherences.

Biogas is a mixture of gases created by microorganisms in the decomposition of organic substances in an anaerobic (oxygen-free) environment. The composition of biogas depends on the biomass used and it is shown in Table 1.

Table 1.1.

Typical composition of biogas, depending on the biomass used [65]

Component		Agricultural waste, %	Landfills, %	Industrial waste, %
Methane	CH_4	50-80	50-80	50-70
Carbon dioxide	CO_2	30-50	20-50	30-50
Hydrogen sulphide	H_2S	0.7	0.1	0.8
Hydrogen	H_2	0-2	0-5	0-2
Nitrogen	N_2O	0-1	0-3	0-1
Oxygen	O_2	0-1	0-1	0-1
Carbon monoxide	CO	0-1	0-1	0-1

Biogas is produced by anaerobic fermentation. Biogas production process is an environmental technology that integrates production, processing and recycling of the degradable by-product issues [66]. Not only does biogas produced by anaerobic digestion prevent greenhouse gas emissions and produce renewable energy, but also provides for the production of processed fertilizers, improving nutrient self-sufficiency in the agricultural sector [67]. The productivity of a biogas plant depends on different aspects, like type of biomass [68], digestion [69], availability of biomass, impurities that may harm microorganisms [70] and lignin content [71].

There are 4 generations of biogas:

- first generation biogas is produced from agricultural crops that can be used in food or fodder;
- second generation biogas is produced from inedible parts of plants, residues from woodworking and forestry, energy crops;
- third generation biogas is produced from macroscopic and microscopic algae;
- fourth generation biogas is produced from modified organisms that are more likely to capture atmospheric carbon dioxide [72].

In addition, in the process of anaerobic digestion it is very important to use co-digestion, which allows to increase the productivity of produced biogas from 25 to 400 % over mono-digestion [73],[74]. Co-digestion is often used for the very reason that the optimal carbon-nitrogen ratio on biogas production is in the rage of 20:1 to 30:1, but in general, manure has very low carbon ratio and it is important to mix it with other substrates that are carbon-rich to increase the biogas yield [75].

1.2.3. Raw materials for biogas production

Supply and storage

The first process required for biogas production is the supply and storage of substrates. Biomass (substrate) is the most important element of the biogas production system. Knowing the composition of biomass, it is possible to predict the ratio of methane and carbon dioxide in biogas composition [76]. Different raw materials can be used as a substrate individually (mono-digestion) or mixed (co-digestion) [75]. Almost any organic material can be used for the biomass production, for example, paper, grass, animal waste, domestic or manufacturing sewage, food waste, agricultural products etc. [76].

The most important thing is to rethink the biomass availability, divisibility and cleanliness so the biomass is free of sand, heavy metals and salts that may harm microorganisms and promote corrosion in metal details and constructions [70]. It is desirable to avoid plants with too high lignin content (such as wood waste), because most of anaerobic bacteria are unbale to split lignin [71]. However, some substrates can be problematic with their various applications, for example, the use of agricultural crops to produce biogas, represents an increase in competition for land use to produce animal or human food [75]. Unlike the competition for land use in the agricultural crop sector, manure needs to be treated to avoid additional GHG emissions in the air. There are studies indicating that the addition of manure is necessary to ensure a sufficient level of micronutrients for the digestion process [75]. There are also an aspect that different types of manure present variation in organic composition and dry matter content (1.5 – 30.0 %), which affects the biogas produced. The manure co-digestion with other substrates can provide that already after the first anaerobic digestion process, dry content is about 10 %. [75] Co-digestion is often used for the very reason that the optimal carbon-nitrogen ratio on biogas production is in the rage of 20:1 to 30:1, but in general, manure has very low carbon ratio and it is important to mix it with other substrates that are carbon-rich to increase the biogas yield [75],[77].

Table 1.2.

Yield of various raw materials [78]

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

Whereas finding new sources of renewable energy production is a global issue [79],[80], at the same time the use of maize for biogas production as a result of differences of opinion on its impact on the environment is being rejected [81], even though maize biogas yields and characteristics are far superior to other crops for biogas production [82],[83]. The most used substrate with manure for co-digestion is maize silage and the reason is shown in Table 1.2. Comparing the biogas yield of maize silage with the biogas yield of liquid cattle manure, biogas yield from maize silage is 8.08 times higher. Not only does maize have a high carbon fixation and assimilation capacity [84], but it can also be grown worldwide due to its high photosynthesis and resource utilization [85], even in conditions of drought, high temperatures and lack of various nutrients [86].

The mode of supply of the substrate can be either periodic or continuous. The periodic feedstock means that biomass is added only at the beginning of the process. The process is started by adding an inoculant and after the start of the process, the bioreactor is closed [76].

In the form of continuous feedstock, biomass is fed in specified intervals or continuously. Thereby the biomass is produced at a constant rate and recycled substrate is also continuously removed from the reactor [76]. Regardless of periodic or continuous feedstock, storage of raw materials is necessary to avoid their shortage due to seasonal availability, which is why bunkers or storage tanks are used, depending on the solid content of the substrate. Although the management of livestock manure through the production of biogas reduce emissions to the atmosphere, there are potential “leakages” of emissions. Nitrogen (N), Nitric oxide (NO), Ammonia (NH_3), CH_4, N_2O and odorant dust can be released in the storage of feedstock and digestate in open tanks, as well as in their treatment [87].

Biomass pre-treatment and fermentation

Biomass pre-treatment is very important to evaluate and purify it to a state where the fermentation process is not disturbed. During the biomass assortment step the inorganic additions and biomass, which contains too much lignin and are inappropriate, are removed [88]. In the next step of substrate preparation the biomass is shredded (if necessary) and the alkaline and acidic materials are mixed [88]. Pasteurization and pressure sterilization are performed prior to the substrate input into the bioreactor [76]. It is very difficult for microbes to break down various chemical bonds during anaerobic digestion. One of such substances is lignin. However, given that the use of maize and rapeseed silage in biogas production will no longer be acceptable, it is necessary to find new raw materials that naturally occur as waste. China is an excellent example in this case. In 2015 China produced more than 787 million tons of cereal straw, of which about 82 % could have been used for biogas production, but instead of energy production, 20.7 % was burned on an open field [33]. To overcome this problem, Chinese researchers came up with a study that high lignin content of straw can be broken down and converted into easy-to-use organic materials by pretreatment [89]. There are many ways to pretreat lignocellulosic substrates with many different physical, chemical, biological methods and combined for anaerobic digestion process and this way increasing biogas yield for even 105.3 % by removing hemicellulose and lignin [33]. Considering that more than a half of Latvia's territory is covered by forests in 2016, but 36.5 % of Latvia's territory is covered by agricultural lands, Latvia has a big potential to use harvesting and agricultural crop residues and waste, which have high levels of lignin in their content [90]. Grasslands have a variety of functions in agriculture – now they are primarily the main source of feed for livestock, but overall they provide benefits such as carbon storage and soil protection from erosion, groundwater formation and habitat formation in diverse landscapes and natural foundations [91]. Although grassland can be used in the production of lignocellulosic bioethanol, synthetic natural gas or synthetic biofuels, according to the Green Biorefineries concept, the sustainable use of grass biomass is directly linked to the production of biogas [91]. Surveys from Germany's and Austria's biogas plants show that grass silage is already used as the second most common crop raw material, right after corn silage [91]. Knowing the feasibility of successful processing of these raw materials and their practical application, it is understandable that these are potential raw materials also in the agricultural conditions of Latvia.

Fermentation process takes place in bioreactors. The decomposition of the biomass can be divided into 4 phases: hydrolysis, acidogenesis, acetogenesis, methanogenesis. In the phase of hydrolysis carbohydrates and proteins are broken down into smaller molecules such as sugars and amino acids, as well as lipids broken down into fatty acids. The next phase is the acidogenesis process, the intermediate process (formed in the hydrolysis) is further degraded to form lower forms of fatty acids, for example, propionic acid. In addition, hydrogen, carbon dioxide and acetic acid (which are the basic elements for the further production of methane) are created in the third phase - acetogenesis. During the acetogenesis, the lower fatty acids are broken down into acetic acid by acetogenic microorganisms. During the last phase archaea (the oldest form of life on earth) convert acetic acid, hydrogen and carbon dioxide into methane and carbon dioxide [92].

Biogas can be obtained by fermentation process (dry) or anaerobic digestion (wet). Gas output is mainly influenced by 5 factors:

- temperature – it must be kept stable to prevent the death of microorganisms. To maintain a constant temperature, bioreactor must be isolated and heated;
- duration of aging– the duration of fermentation depends on the material to be recycled and the mode;
- presence of air – it is not allowed in anaerobic processes;

- composition of microorganisms (a carbon and nitrogen ratio of less than 43:1 is desirable (optimally around 20, as well as carbon and phosphorus ratio of less than 187:1 is desirable) [78];
- pH level – preferably between 6.0 and 8.0 (optimally 7.0).

As the bioreactor is completely closed, no emissions should occur, however in the operation of a biogas plant, instances of excess pressure might occur, and in these processes pressure valves might release ~1 % of gas produced. For GHG calculations, these losses are important, as ~60 % of the gas volume is methane and the concentration of ammonia (NH_3) in biogas is 0.1 – 1.0 %. For most digestion processes leakage losses will be less than 0.05 % of nitrogen (N) of the resulting digestate, therefore it is not considered as relevant. Emissions of nitric oxide (NO), dust and odor from anaerobic digestion in biogas facilities are likely to be insignificant and are not taken into account [87]. Anaerobic digestion has been mainly implemented for the management of animal manure, organic and agricultural waste, sewage sludge, plant green mass etc. [93]. Theoretically it is possible to use forest and wood processing waste and peat [94].

Manure is the most suitable material for biogas production. The easiest way to get biogas is from cattle manure. The dry matter content of the manure depends on the used amount of litter, moreover if a lot of washing water is used, the manure is watery. There is a study that proves that in the ratio of cattle manure (1) : water (3), the system produce the highest volume of biogas and it can be explained since water addition is necessary to fulfill the need of water molecules to support the hydrolysis reaction and acetogenesis stage [95].

Pig manure is also very suitable for biogas production, because it contains not only manure, but also feed residues and litter. Bird manure is very suitable for biogas production also, but there tend to be sand, and feathers mixed in, which can cause problems, when specially adopted pumps are not used. Because of the high concentration of nitrogen, it is advisable to mix them with cattle manure [94].

Anaerobic processes can occur in manure with both high and low moisture content. Processes are faster in fluids, that is why water must be added to the dry waste [94]. One of the main factors influencing the methane fermentation process is temperature. There are 3 different temperature regimes: Psychrophilic (15 – 30 °C); Mesophilic (31 – 42 °C); Thermophilic (48 – 60 °C) [96]. There is still debated as to which temperature regime is better- mesophilic or thermophilic. Although the thermophile process consumes more heat than mesophilic, it gives more biogas production in a shorter time and, most importantly, provides complete sanitation of the processed manure, which is an important aspect for field fertilization [94]. It is important to note that fields with untreated manure may only be treated after at least 8 months of holding, because in that time period pathogenic microorganisms die [94].

1.2.4. Application of biogas

The conversion of biogas to biomethane and its use as vehicle fuel has greater potential and greater justification than biogas combustion [97] in CHP unit. Since 2016, Latvia has adopted a law that it is possible to inject biomethane into the natural gas network, but the regulation on methane concentration, which must be more than 90 %, as well as other quality characteristics, is very difficult to achieve [98], in turn, the technologies require investments, as well as infrastructure or tax incentives, but the state does not support it, yet provides a tax on it [99].

At the same time as biogas cogeneration plants have undergone changes, tightening restrictions, reducing financial support, politicians have issued a new announcement about the plans of the beginning of the biomethane era in Latvia [100]. Biomethane is planned to be introduced into the common natural gas network, while the consumption of the product is planned to be guaranteed by purchasing biomethane – powered school buses, agricultural tractors and fire trucks using the new European money to recover from the Covid-19 crisis [100]. However, the production of biomethane requires treatment plants, which would be co-financed by European funds for the current period, but with the support of Cohesion policy, a gas connection and transmission network, filling infrastructure would be built [100].

The need to develop the biogas sector, as well as to transform it into biomethane, is indicated not only by the Paris Agreement and Green Deal, but also by several plans developed at the national level. The Latvian National Energy and Climate Plan (NECP) clearly indicate the aim to reduce energy dependency on third countries, eliminating energy poverty risks and promote public welfare in general to move to a sustainable, climate neutral and internationally competitive economy [101]. One of the main policy directions set out is the use of biogas resources and promotion of the production of biogas and biomethane to move towards fully decarbonized energy sector, including transport sector [101]. The plan includes several goals in the field of energy decarbonization, one of which is to promote the production and use of biogas and biomethane, achieving the use of biomethane in the amount of at least 3 – 5 % of the energy used in transport final consumption in 2030 [101]. Examining the relationship of the plan's context with the current Latvian and their policy planning documents on decarbonization and renewable energy issues, the link with at least 10 documents can be seen, for example:

- SDSL2030 (Latvia's sustainable development strategy for 2030), which emphasizes:
    - development of energy interconnections and decentralized energy production;
    - use of renewable energy sources and innovation, including use of biomass for electricity and heat production, use of biogas resources and biofuels;
    - supports environmentally friendly transport policy, innovation and modernization in agriculture and use of biomass [101],[102];
- LTESL2030 (Latvian energy long-term strategy 2030 – Competitive energy for society), which reports on the need to promote:
    - wider use of renewable energy sources in public transport;
    - the use of waste for energy production to increase the use of local energy resources at the same time solving the waste utilization;
    - the development of natural gas supply and storage infrastructure [101],[103].
- Rural Development Program of Latvia 2014–2020, which motivates to:
    - improve fertilizer and pesticide management;
    - use of waste materials and development of bioeconomy;

- reduce greenhouse gas and ammonia emissions from agriculture [101],[104].

There is another policy planning document – National Industrial Policy Guidelines (NIP) - , which sets out directions for action for the next seven years, motivates Latvian producers to develop competitive advantages related to technology and innovation, while working to make Latvian industry more environmentally friendly, as the insufficient level of technological development is mentioned as one of the Causes of low productivity in Latvia. While there are various obstacles to such a transformation, including the crisis caused by Covid-19, it is an opportunity to change habits and focus resources on future growth in sectors and industries, maintaining a strategic course and accelerating productivity-based economic restructuring. As Latvia has identified five knowledge-intensive areas, where both resources and expertise are available, two of which are smart energy and mobility, as well as the knowledge-intensive bioeconomy, these areas have been at the forefront of discussions in industrial policy, considering future transformative nature and higher added value activities. Thus, the introduction of the concept of Smart Specialization (RIS3) in research and innovation strategies implies the constant finding of competitive advantages, considering environmental protection and climate development.

These documents make clear the importance of biogas and biomethane for the future, which is also part of the bioeconomy system, the main aim of which is to find new ways to produce and consume resources away from a linear economy based on the extensive use of fossil fuels and minerals [105]. In addition, the production of biogas or biomethane directly produces not only green energy, but also digestate as a by-product containing a significant amount of nutrients, which is suitable for fertilization [106], which is one of the biggest benefits of biogas production, because fertilizing the fields with digestate can indirectly reduce greenhouse gas emissions, for example, a digestate, derived from 1 ha of corn green matter provides full potassium for the field fertilization and saves 31 % phosphorus and 44-45 % nitrogen [107]. So it has ability to reduce nitrogen fertilizer amount, in addition, the precise use of the necessary fertilizers also reduces nitrous oxide emissions by reducing nitrogen levels [108]. This increases the uptake of carbon dioxide through higher productivity and the introduction of biomass into the soil. [108]

Despite the political goals, there are several concerns about putting the biomethane idea into practice in Latvia and one of the biggest concerns is investments required in the compression equipment, so the biomethane could be transported to another company or place for the use in vehicles. Biomethane transportation by trucks works as an alternative, if the biogas plants is not close to the natural gas network [109],[110]. But it has to be compressed to 200 bars to be used as a fuel, and 200–250 bars to be transported by trucks [109]. As Latvia plans to use biomethane in heavy vehicles, it is also necessary to dilute it, because then the energy density is much higher and therefore longer distances can be reached with the same fuel storage capacity [109] .

Figure 1.1 perfectly represents the factors that must be considered for biogas production to be full-fledged and maximally economically beneficial. As it is well known, traditional energy prices are low, but over time the role of heat production may increase if more and more electricity is obtained from non-combustion processes [55]. Meanwhile better short term profitability is expected from the use of biomethane as a traffic fuel [55].

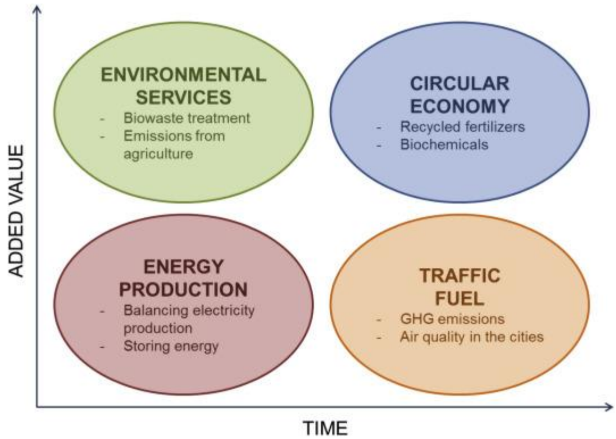


Fig. 1.1. Opportunities in biogas production – from energy to circular economy [55].

Production of recycled nutrients and biochemicals are seen as a future possibility [55]. But the turning point could be the new incentive through greenhouse gas emission trading scheme for farm-scale renewable energy production (a market that pays for carbon sinks in agricultural land) - carbon farming.

1.3. Carbon Farming

The European Parliament has announced that a new business model for farmers and foresters called Carbon Farming is being promoted that includes practices that remove carbon dioxide from the atmosphere and store it in the ground [111]. The Carbon Farming initiative concludes that Carbon farming can significantly contribute to climate change mitigation, and the European Commission acknowledges that Carbon farming is in its infancy and that there is a lot to be addressed [112]. The European Commission highlights that Carbon farming can be promoted via EU and national policies and private initiatives and in the years towards 2030, result-based Carbon farming pilots and, eventually, schemes should be settled by Member States and local governments [112].

Carbon is the atom of life and not only by carbon-based fossil fuels our vehicles, homes, and factories are powered, but it's also used in chemicals, plastics, advanced materials, steel of our cities involves processing carbon, half of the food is carbon, it is even in human DNA [113]. However, the concentration of carbon dioxide in the atmosphere has increased significantly, mainly due to the combustion of fossil fuels in industrial processes [114] and the activities of various other sectors [115],[116].

Carbon dioxide (CO_2) is a renewable [117], inexpensive [118], safe gas with a balanced geographic distribution [119], mainly known as a greenhouse gas that significantly contributes to global warming [120]. Although CO_2 is a relatively low energy and inert molecule, its involvement consumes much energy and not enough developed processes [119]. Therefore, it is essential to identify the directions with the most significant potential for the sustainable and efficient use of CO_2 in production rather than negatively impacting the economy and the environment.

Although negatively impacting utilization will not significantly reduce global warming [121], more and more research has come up with different solutions for using CO_2 in various industries' production processes, replacing fossil fuels, for example, in chemistry [122], transport [123], food production and processing [124], in the production of various daily necessities [125],[126], thereby promoting sustainable development and reducing greenhouse gas emissions in the atmosphere.

To move on with the European Green Deal ambitions, EC proposes to revise relevant climate policies, for example, targets to reduce emissions in sectors outside the EU ETS [127]. Reaching these ambitions will require action by all sectors of the economy, including agriculture; nevertheless, it is not so easy. One of the main challenges facing the agricultural industry is to provide food for the increasing population while reducing its influence on the climate and environment. Therefore, carbon farming mainly aims to trap carbon in soil and vegetation because of the co-benefits of fertility and productivity boost [128].

As an increasing number of private carbon initiatives have emerged, where land managers sell carbon credits on voluntary carbon markets, it is the right moment to improve high-quality supply in the EU. The best practice would be to prevent a large-scale lift-off and ensure adequate reward for the carbon credits, but on the supply side, carbon farming credits should become an additional "product" for sale [129]. It would be a new source of income for land managers.

1.3.1. The current level of research of carbon farming solutions

To evaluate the current state of carbon farming (a market that pays for carbon sinks in agricultural land) and how it is connected to other topicalities and the leading technologies used to achieve it, a bibliometric analysis using VOSviewer© was conducted. Scientific publications on the Scopus database with the keywords "carbon farming" and "agriculture" were searched. Fifty-three publications were found with these two terms with 50 keywords when a co-occurrence constraint of at least five co-occurrences is considered. This means the bibliometric network presented in Fig. 1.2.a. displays those keywords that appear at least five times within the publications. The links displayed between items represent a co-occurrence in a source, each connection with a strength score; the higher the value, the stronger the association. Such a strength score represents the number of publications in which both keywords appear together (co-occurrence) [130].

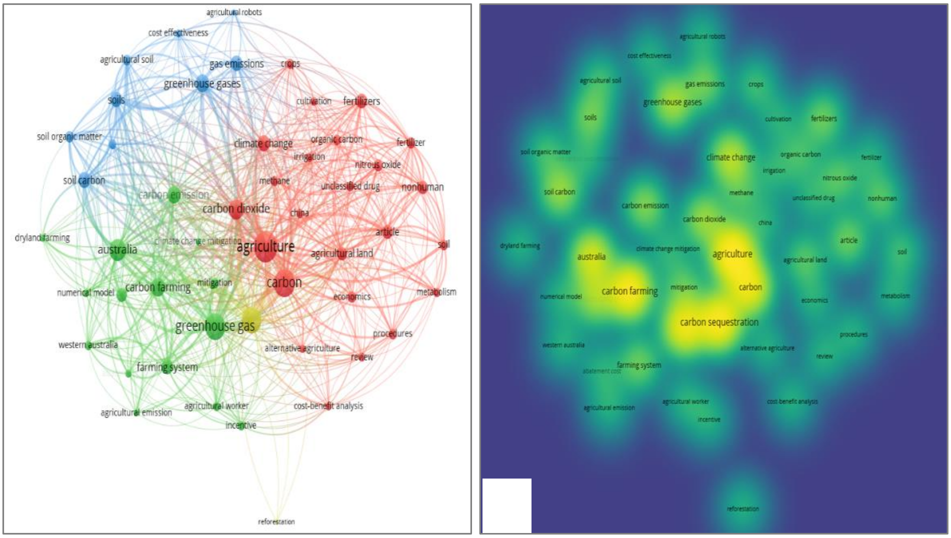


Fig. 1.2. a) Network visualization. b) Density visualization.

Fig. 1.2. b. shows the occurrences density visualization of each keyword for the network, with "carbon sequestration", "carbon farming", agriculture", "carbon", and "Australia" being the most common items. When the "carbon farming" keyword is analyzed within the network (see Figure 1.3.a), the main topics connected to it are shown, some of them of importance to this work as some techniques are observed. The yellow cluster for instance (see Figure 1.3.b), displays two current technologies, carbon sequestration with occurrences in 18 out of 50 publications and 46 links, and reforestation with only three occurrences and four links.

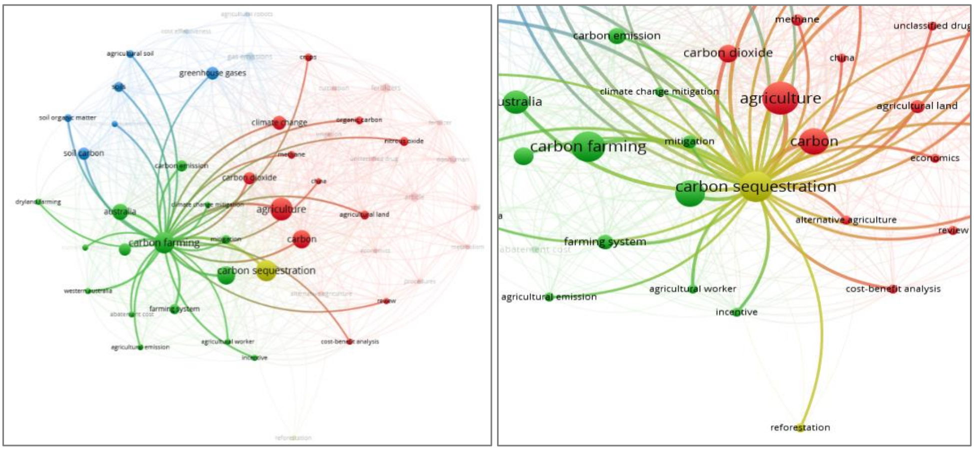


Fig. 1.3. Carbon farming links and relationships.

Another interesting analysis from the network is the fact that the link between "carbon farming" and "agriculture" does not have considerable strength in the network with a score of 5, with the stronger links to exists among "carbon", "agriculture", and "carbon sequestration" showing scores between 9 and 13. When it comes to deep research on carbon farming techniques, the lack of related keywords in this network is noticeable, with most studies focusing on types of crops, economic evaluations, and GHG emissions.

To achieve the goal of this research – to identify carbon farming solutions for Latvian conditions and determine their importance in reducing GHG emissions, a literature review has been conducted, mainly analyzing reports, legislation, scientific articles that were identified as a relevant material to provide an understanding of some of the possible solutions for carbon farming in the Latvian agriculture sector. The search was performed mainly using Google, ScienceDirect, Web of Science, and Google Scholar. The review was done based on the agricultural situation of Latvia, but it can be used for other countries too.

In 2018, only 1 % of the approximately one billion tons of biogenic (45 %) and fossil (54 %) carbon was recycled [131]. Fossil carbon should be replaced by carbon derived from waste, the atmosphere, and sustainably harvested biomass, to produce such products as plastics, synthetic fuels, rubber, and various value-added materials and chemicals [131]. Biogenic carbon will play an essential role in construction, providing substitutes for conventional building materials with alternative materials that can store carbon long [131].

It can already be seen that by 2030, the Innovation Fund will provide financial support of 25 billion € (at a carbon price of 50 €/tCO_2) for companies to invest in clean technologies, carbon capture and utilization (CCU), carbon capture and storage (CCS), and carbon sequestration [131]. To achieve climate neutrality by 2050, each CO_2 eq ton emitted into the atmosphere will have to be balanced by a ton of CO_2 captured in the atmosphere. It means significantly reducing emissions and increasing carbon sequestration as an input to the production of various products.

1.3.2. Practical carbon farming solutions in the case of Latvia

Zero / Minimal Tillage

In 2018, 59.3 % of all emissions in the Latvian agricultural sector were caused by tillage, and 57.2% of the arable land and these lands are occupied by cereals, which makes it a priority for the necessary change [132]. It is important to note that the treatment of agricultural soils includes emissions from the use of tractors and the use of fertilizers and post-harvest residues, which are later incorporated into the soil [133],[134].

The Strategic Plan of Latvia's Common Agricultural Policy also attaches great importance to reducing GHG emissions from agricultural land management by promoting more sustainable practices. The main aim of the activity is to encourage the use of sustainable agricultural production methods in the management of agricultural lands. It includes precise, well-thought-out fertilizers and plant protection, the cultivation of a single crop in a defined area for a maximum of 3 consecutive years, and the provision of green cover during part of the perennial planting area the growth season.

Reducing emissions from post-harvest residues is unfortunately not possible, as although, in theory, these residues could be collected and used in biogas or biofuel production with a 28 % reduction of GHG emissions, this is by no means acceptable, as it would have a negative impact not only on soil quality but also on the environment as a whole [135]. Even if crop residues are harvested below 25 %, it can lead to segment losses during the rain. Therefore studies show that only a minimal proportion can be removed, but it would be neither economically justified nor rational [136]. It means that the emphasis must be on reducing emissions from fuels and fertilizers; in addition, studies have shown that fuels and fertilizers are responsible for most of the GHG emissions from the agricultural tillage [137],[138].

Although high hopes are for electric tractor development, it is essential to look for solutions today. One solution is a sustainable agriculture technology based on reduced tillage to preserve soil structure and organic matter – minimal or even zero tillage [139].

In Europe, minimum and zero tillage methods have been used for decades. Still, in Latvia, 91.2 % of soils are cultivated with conventional tillage, while the energy consumption of this technology is 26 % higher than at minimal tillage and 41 % higher than at zero tillage [140].

To achieve sustainable agriculture and save emissions, various activities must be carried out in several stages, one stage lasting at least two years and consisting of 4 steps:

- minimum treatment methods are introduced (plowing is stopped);
- under the influence of organic matter, the soil is improved due to the decomposition of crop residues, but the number of pests increases, which must be controlled with the help of chemicals;
- the common system is stabilized, and the diversification of cultivation systems is introduced with intercultural cultivation;
- the new farming system strikes a balance that can improve productivity compared to conventional farming and reduce the need for fertilizers and plant protection products [139].

Although the introduction of such a system takes an average of 6 years and yields during those six years can be significantly reduced, GHG emissions would be saved considerably and eliminated by reducing the amount of diesel and labor used, as well as fertilizers and plant protection products, in addition, the potential income from carbon farming would make such shift more motivating for farmers [141],[142]. Faster results can be achieved with the most modern seed drills without plowing technology, where the seeds are pressed directly into the ground with a particular disc. Because direct sowing does not require many processes, the cost of working hours, fuel, spare parts, and repairs, and operating costs are reduced when productivity is not reduced [142],[143]. When choosing this technology, it is most important to pay attention to the sown interculture because it is the intercropping that provides the necessary minerals to the soil and creates micro-reclamation with plant roofs, preventing the soil from drying out or leaching fertilizer [143]. Choosing the right intercultures makes it possible to control weeds and various diseases, resulting in a significant reduction in the need for plant protection products [143].

Biogas production

The importance of renewable energy development for the decarbonization of the energy sector is already recognized [144], and biogas production is particularly suitable for Latvia because agriculture in Latvia accounts for 24.6 % of total GHGs, ranking as the 2nd largest GHG emitting sector [145]. Biogas produced by anaerobic digestion prevent greenhouse gas emissions and produce renewable energy from waste and provide for the production of processed fertilizers, improving nutrient self-sufficiency in the agricultural sector [67]. After biogas extraction, it has mainly two options for further use – its combustion to provide heat and electricity at cogeneration plants or to upgrade to biomethane to use it as a road fuel [72],[92],[146]. Both in Europe and Latvia, the industrial use of biogas is based on power generation through combined heat and power units [59][51].

The productivity of a biogas plant depends on different aspects, like the type of biomass [68], digestion [69], availability of biomass, impurities that may harm microorganisms [70], and lignin content [71]. Unlike the competition for land use in the agricultural crop sector, manure needs to be treated to avoid GHG emissions in the air. Studies indicate that the addition of manure is necessary to ensure a sufficient level of micronutrients for the digestion process [75]. Biomass pre-treatment is also essential to evaluate and purify it to a state where the fermentation process is not disturbed. Biogas production process is described more in detail previously in literature review. To conclude, it is important to note that fields with untreated manure may only be treated after at least eight months of holding because, during that period, pathogenic microorganisms die [94]. It is one more reason why it is so essential to develop biogas production and reduce not only emissions but also reduce environmental pollution risks - it is one of the most critical co-benefits of the carbon farming [147].

Biomethane

Decarbonization and gasification of the transport sector is currently the most topical topic for the Latvian policymakers because Latvia, along with the other EU Member States, must ensure that the share of renewable energy in the final energy consumption in 2030 reaches 14 % (the target for this in 2020 is a 10 % share). Still, only 4.7 % were achieved in 2018 [39]. Renewable energy production will increase with a particular focus on solar panels, collectors, and wind energy, however, it will not be technologically possible due to storage issues [31]. Given that around 6 million tons of agricultural waste are produced yearly, the pathways and strategic priorities for the transition to a net-zero GHG emission economy provide a promising future for the development of biogas production, especially for upgraded biogas to biomethane, which is flexible both in use and storage and because its production from agricultural and industrial waste, sewage sludge, it also protects soil, air, and water from the pollution [32],[33]. Assuming the annual biomethane production from anaerobic digestion in the European Union was 2.3 billion m^3, it is estimated that it could reach 64.2 billion m^3 by 2050 in the case of an optimized gas scenario [144].

The biogas sector is already well developed, and huge investments have been made. Still, the industry is currently highly financially dependent on state aid, and biomethane (product with higher added value) production seems to be a way to reach financial independence and profitability [144]. Biogas can be processed to biomethane and used as a road fuel or for sale on the natural gas network. Unlike natural gas, which is a fossil fuel, biomethane is a renewable fuel, which is emission neutral or even negative [148]. There are different methods for biogas upgrades, but the main aim is to separate methane from carbon dioxide, so it could be used for fuel, also heating, electricity [149].

Since the raw gas contains approximately 65 % methane and 35 % carbon dioxide in the volume, the acquisition of biomethane is measurable on average at 63 % [150]. Therefore, it is possible to produce hydrogen from the carbon dioxide separated from biogas and used it as a transportation fuel and electricity [151],[152]. The practical efficiency of carbon dioxide conversion is 47.7 % with a hybrid Na-CO_2 cell [152]. According to the Central Statistical Bureau, 11 million m^3 of biogas was produced in 2018. If all this biogas were used for methane production, 6.93 million m^3 of biomethane would be made with 63 % efficiency. In contrast, an additional methane yield would be produced during the hydrogen methanation process from the rest of the biogas, which contains 35 % carbon dioxide. Biological hydrogen methanation could increase the biomethane yield and lower the costs for biogas upgrading to natural gas quality [153]. The efficiency of the process in a cogeneration plant right after the methanation is 30–45 % (37.5 % on average) [153], which means that if 4.07 million m^3 carbon dioxide is produced, then with biological hydrogen methanation digesters, it is possible to maintain 1.83 million m^3 of methane. Knowing that 1 l of diesel equals 1 m^3 of biomethane, which is 10 kWh in the energy [154], the potential impact on the environment would be 1.83 million l of saved diesel fuel.

Capture by soils

Carbon sequestration comprises several techniques that aim to reduce CO_2 emissions and CO_2 concentration in the air [46]. Such methods are also called Direct Air Capture (DAC), Direct air carbon dioxide capture and storage (DACCS), and Carbon dioxide removal (CDR). Carbon sequestration by using these techniques is of vital importance. It has been reported in the AR6 IPCC [155] that without them, it is impossible to limit global warming to 1.5 ºC in the Shared Socioeconomic Pathways (SSPs), where sustainable development and international cooperation are ground rocks.

Carbon sequestration by agricultural-related products and techniques is under the umbrella of biological CDR methods [155]. They aim to increase carbon storage on land by boosting primary productivity while reducing CO_2 in the atmosphere. Within CDR methods, some forest-based ones (such as afforestation and reforestation) are not risk-free [156] and are susceptible to droughts, fires, plagues, diseases, and others [157]. Therefore, the IPCC has placed a high confidence level in other alternatives for carbon sequestration, such as secondary forest regrowth, non-forest ecosystems restoration, and improved practices in agriculture and grasslands [158],[159],[160],[161].

Furthermore, improving agricultural management practices can offset soil carbon losses by fixing a large share of the historically lost carbon back in the soil [162]. Some of the most effective enhanced agricultural methods to increase soil carbon content are the crop rotation cycles and the use of crop cover to avoid periods of bare soil [163], residue management and grazing optimization [164], agroforestry, reducing grassland conversion, recycling of crop's nutrients and the use of irrigation [164],[165]. These methods can also improve soil fertility and minimize nitrogen emissions unless an increase in fertilizers is employed [166].

Still, many other methods can be classified as carbon sequestration but are not necessarily linked to agricultural practices. These can include using biochar to improve soil quality

and crop yield [167] and enhance the water holding capacity. Peatland restoration is another technique for increasing the land area of CO_2 sinks. However, it increases methane emissions from the created anoxic conditions. Finally, bioenergy with carbon capture and storage (BECCS) is a technique counting on the carbon neutrality of energy production. It relies on the idea of bioenergy production, where the amount of CO_2 emitted during the combustion is as much as the carbon fixed in the growing biomass used as feedstock [168]. BECCS claims more importance if such emissions are also captured and stored, creating a net negative emission effect in the atmosphere [168].

Overall, there are many CDR methods for carbon sequestration, with a broad spectrum of effects on the soil and water quality that might affect crop yield and biodiversity. Nevertheless, many of these methods have proven to bring further benefits to natural ecosystems while promoting harmful emissions.

Perennial plants

Perennial plants make most of the planet's plant species, yet those grain crops for human consumption are not. Annual plants die each year and must be replanted, shortening the carbon cycle time in those areas where they are grown. However, there exist options to grow grain from perennial crops, as is the case for some oilseeds and cereals able to grow in deserts shrubs or seawater [169].

The main advantage that perennial crops bring over annuals is their capacity to distribute more resources underground than in the seeds [80], making these plants a perfect candidate for soil carbon sequestration. Moreover, some perennials can also grow sizeable underground, providing additional ecosystem services such as erosion reduction and a decrease in water and nutrient losses [169]. Thus, a shift to perennial grain crops has been encouraged in the last two decades as part of sustainable agriculture practices [170].

But perennial crops for grains are not the only alternative for carbon sequestration in agriculture. Perennial grasses can also be used in multifunctional agriculture. Those additional non-conventional products can provide ecosystem functionalities and renewable energy production and promote sustainable development in rural areas. The main setback of these crops is the early stage of domestication and development, which means an unexploited potential for carbon sequestration.

Also, perennial grasses can be used to enrich the soil by the conversion of croplands to permanent pastures, which inevitably results in higher carbon fixation in the grounds. Additionally, perennial grasses can reduce soil organic carbon via erosion cover if compared to annual grasses [165]. Also, perennial grasses and crops are more resistant to unfavorable climate conditions thanks to more robust storage structures like roots and rhizomes, making them an excellent alternative to improve agriculture resilience and food security [165].

In conclusion, perennials are a promising alternative to boost carbon sequestration and agriculture multifunctionality while delivering additional ecosystem services.

Agroforestry

Agroforestry is a practice where perennial tree and shrub planting is combined with crops and/or animals in the same unit of land [171]. Although the term "agroforestry" is relatively new, the practice is ancient and should return to farmers' daily practices today [172].

It is one of the ways to ensure the self-sufficiency of agriculture by reducing the consumption of fossil resources and increasing the extraction of various products. As globally agroforestry is practiced mainly by smallholder farms [173], it could be a solution in Latvia's case because 26 % of agricultural lands are owned by smallholder farms [134] that might not be able to invest in new technologies. In contrast, it would be possible to enhance income generation and security with an agroforestry system.

It is considered a dynamic and ecologically based system that diversifies production and increases social, economic, and environmental benefits [172]. It has been proved to reduce soil erosion and improve soil condition, increase resilience to weather changes, and increase biodiversity and carbon capture by trees and soils [165]. When tree species are deliberately planted, such a system can not only provide many benefits for crop cultivation but also improve agriculture productivity by providing additional products, like fruits, berries, and nuts, also fuelwood, which allows reducing dependency on local forests and if livestock is involved in the system, it provides fodder [174]. In livestock agroforestry systems, trees can serve as a shelter from winds and heat, which is especially important for dairy cattle to increase milk yields; also, depending on the tree species, it can provide additional feed full of minerals and protein [175].

But as agroforestry leads to a generation of an ample amount of agroforestry waste, biorefinery must be considered for effective management of residues in products with higher added value as biofuels, fertilizers, and biochar and industrial chemicals [167].

1.4. Energy management and efficient use of resources

The agriculture sector keeps an essential role both in global and in Latvia's economy and is crucial to economic growth. However, rural areas are those that often have enormous, but rarely fully realized economic potential. Energy efficiency trends in the agricultural sector also point to necessary improvements in the whole EU [176]. Although the farming practices of Latvian farmers can be assessed as positive not only because of the high-quality products, but also because of productivity, the energy efficiency trends of the agricultural sector point to necessary improvements. This is because energy efficiency has not reached the EU average over the last 8 years [177]. Furthermore, Latvia's indicators show much larger fluctuation both in the turnover of the produced products and in the energy efficiency of the agricultural sector [177].

To increase energy efficiency, it is necessary to introduce energy management, which is a reasonable and efficient use of energy to maximize profits by reducing costs. In addition, energy management is related not only to the economic aspect, but also the environmental aspect, in order to eliminate inefficient use of resources, which in turn causes global warming [178]. However, the main problem is the large proportion of hard-to-reduce greenhouse gas (GHG) emission sources, which is the main characteristic of this sector [101]. Both in Europe and Latvia, the agricultural sector is one of the largest sectors producing GHG emissions (382.45 and 0.1 million tons of CO_2eq) with high potential for productivity and efficiency improvements [179],[180]. Although agriculture captures carbon dioxide in the process of plant growth, emissions are also generated in many processes, for instance, intestinal fermentation processes of farm animals, manure management, agricultural soil treatment, liming and urea use, fuel use for field cultivation, energy use in various processes, etc. [40].

Agriculture is in the most direct contact with natural resources - water, land, plants, animals, natural minerals, energy - and is directly and indirectly linked to all other sectors [7]. Not only its connection with other sectors, all kinds of resources, but also the diversity of its activity makes it a very complex, difficult sector to organize, but it is a very important investment both in terms of environmental and also in economic development [8],[9]. Inclusive, sustainable, growth-promoting and equitable development of all sub-sectors of agriculture could not only have a large impact on an agricultural sector itself, but also other sectors in which it is necessary to reduce GHG emissions [13],[14]. As many of the resources used in agriculture are depletable, it is crucial to find methods to ensure their efficient management and their sustainability and availability in the future [181]. It is crucial to implement energy efficiency and resource efficiency measures without simultaneously reducing productivity [12]. However, these energy efficiency measures in the agricultural sector often require large investments in new technologies, and saving on such factors as lighting intensity, heat energy consumption and the economy of various resources is not possible, as it could potentially threaten the existence of the companies due to reduced or possibly even non-existent harvests. Agriculture is a sector subject to technological processes whose application has a direct impact on the production of competitive products with higher added value [182].

Undeniably the adopted policy has a great influence on the direction of agriculture. Although the goal and meaning of the green course are unified [183], the common agricultural policy is developed individually by the member states [184]. The new common agricultural policy envisages making EU agriculture fairer, greener, more results-oriented, as well as guaranteeing stable farmers' incomes and protection against bad harvest years and market price fluctuations [185]. The direction of the transformation is influenced by different strategies.

Climate Neutrality Strategy 2050 aims to achieve climate neutrality by 2050 through improvements in key GHG-emitting sectors [186]. Action measures to achieve the goal planned in the strategy are to achieve resource-efficient agriculture that produces products with high added value and high productivity and increase agricultural investment in bioenergy. "Farm to Fork" strategy aims to make food systems: environmentally friendly (neutral or even positive impact); not only help to mitigate climate change, but also adapt to it; reverse the loss of biodiversity; ensure food security and equity; foster competitiveness and promote a fair trade

[187]. It sets specific targets, such as halving the use of pesticides, reducing fertilizers by at least 20 %, increasing the area of organic farming by 25 % and reducing antimicrobials used on farm animals by 50 %. Another one is the new Biodiversity Strategy for 2030, which is a comprehensive, systemic and ambitious long-term plan to protect nature, stop ecosystem degradation and restore degraded ecosystems [188]. In the light of the Green Deal and its 'Farm to Fork' and 'Biodiversity' strategies, the EU aims to find new ways to decrease GHG emissions through a new approach for Europe - the EU Carbon Farming initiative (described previously in the work), stating that farming practices that remove CO_2 from the atmosphere should be rewarded in line with the development of new EU business models [189]. Also the National Energy and Climate Plan (NECP) for 2030, within the framework of which there is a desire to achieve sustainable land management, farming of agricultural crops and farm animals, respecting the climate, nature protection, economic and social aspects, to make a significant contribution to bioenergy in the field, without endangering food security and CO_2 sequestration and following the cascade principle; to achieve high productivity through efficient use of bio-resources (including land resources) [190].

For instance, NECP's planned measures related to animal husbandry are: improvement of the manure management system for more efficient use of fertilizers, which is essential both from the plant yield and the environmental aspect; To implement manure fermentation biogas reactors, which have the potential to reduce GHG emissions to a minimum in large farms, ensuring efficient manure management and production of renewable energy and valuable fertilizer for crops; To improve animal feeding – various methods are known and used in the world for determining the digestibility of fodder, as well as for determining and analyzing the amount of gases released by animals, balanced and appropriate feed affects the rate of N release from manure, which has a positive effect on the reduction of N_2O emissions, meanwhile improving feed quality increases feed digestibility and reduces CH_4 emissions. Thoughtful, sustainable management would improve the rural population and the well-being of the inhabitants; besides, the fertility of the land would not be reduced, the yield of crops would be increased and the demand for energy from external resources would be reduced. It would not only reduce the impact on the environment, but also promote the competitiveness of local companies in the market by reducing expenses, producing products with higher added value, making full use of all available resources. However, unprofessionally adopted policies that focus only on specific agricultural sub-sectors or groups of companies, may not only prevent these goals, but may even delay them. It should be taken into account that agriculture is a very complex system in which simple saving measures and knowledge are not enough, because various innovations and technologies are needed in order to achieve these savings and productivity [15].

Although the planned measures are theoretically very promising, there is a huge resistance of farmers, where the prevailing opinion is about the inequality and destruction of business in the agricultural sector, the inability to compete. Due to the complicated structure of the sector, it tends to be very difficult or even impossible to determine the real obstacles and mistakes that delay the progress of sustainable farming.

1.5. Higher added value agriculture

Rapid population and economic growth increases the consumption of a large array of natural resources, while simultaneously causing pressure on climate, ecosystems, and biodiversity [191],[192]. In regard to these pressures, bioeconomy is an essential part of sustainable development in line with ecological needs and the limits of planet – not only it would reduce organic waste, emissions, but also increase food safety, reduce concerns of biomass scarcity, etc. [193]. The development of bioeconomy also contributes to the implementation of European Green Deal targets that foresee the use of renewable resources from agriculture and inclusion of residues and waste to produce food, feed, materials and energy [194]. Bioeconomy strategy has two currently relevant stages: medium-term scenario target till 2030 and long-term target till 2050 [195]. It is predicted that a sustainable bioeconomy will thrive via developing a circular economy by not only sustainable production, but also using biowaste as a raw material for new product with the highest possible added value production; implementing a systemic approach that reduces food waste and provides safe and nutritious food; changing the consumers' mindset towards more sustainable consumption patterns; creating new innovative uses of biological resources; implementing a bioeconomy with a sound industrial base that has reduced dependence on fossil resources [196].

Agriculture is one of the sectors that yield a great volume of biomass and biological waste for higher added value production, that could limit climate change, strengthen European competitiveness, reduce both energy and non-renewable resource dependence, ensure food safety [197],[198], however, more determined legislation incentives, operational rules, the involvement of stakeholders and research and innovations at the EU national level are required [199]. It is an industry subject to technological processes, the application of which directly affects the production of a competitive product [182],[12].

For further development of the bioeconomy, it is relevant to expand biorefineries, as these are the multifunctional system that turns biomass into beneficial products [200]. Biorefineries depend on the amount of feedstock produced that can be used to produce higher added value by-products [201]. The research on scenarios for the development of biorefining and valorization of bioresources is helpful in further bioeconomy policy planning. Evaluation of divergent aspects linked to biorefinery implementation are obligatory prior the setting of national bioeconomy goals for specific added value thresholds. Thus, the main aim of the research is to evaluate the contribution of animal husbandry bioresources to bioeconomy development at the national scale. Although agriculture plays a huge role in any economy, especially because it produces essential goods and demand is constantly growing, the growth of the agricultural sector lags slightly behind the growth of other sectors, as its potential is underutilized – currently it is very important to increase not only productivity, but also the added value of agricultural products, moreover, it is very characteristic of agriculture not only in Latvia, but throughout Europe [176]. In addition, it is currently especially important to pay attention to the livestock sector in Latvian agriculture, because lower profitability compared to plant cultivation on field, therefore, the aim of this study is to discover the least cost solution to achieve 30% added value in animal husbandry sector of Latvia in 2030 with help of new products with higher added value, which are produced from current product residuals.

This means that it is important for all agricultural sub-sectors, including greenhouse crop cultivation and other sub-sectors not mentioned in this work, to achieve long-term sustainability to become more and more competitive, and it is possible by implementing an energy-efficient and resource-efficient management system that can be implemented in absolutely any agricultural enterprise. It also means accurate, full, and efficient use of all resources with maximum reduction of residual products. To assess how such a management model would affect the agricultural sector, a model was created specifically for the livestock sector to find out the potential of using residual products. Although not all products were used due to the limited domestic market, a huge potential for increasing the added value of the livestock sector was shown, reaching 62 % higher cumulative added value from 2023 to 2030 with the production of new products – protein powder, pellets, and gelatin, compared to the baseline scenario. Since energy efficiency and the use of waste products in agriculture are not enough, since it is often impossible to economize resources to achieve maximum yield, a system dynamics model for a dairy enterprise was created, which can be easily adapted to any agricultural enterprise. It considered both technological, environmental, and economic aspects, with an emphasis on not reducing productivity at the expense of introducing more environmentally friendly technologies. This showed how important is the company's ability to invest in new technologies, the correct and smart creation of the state policy and support system, because the plans of the strategic documents to date are not enough – currently the emphasis in animal husbandry is directly on reducing manure emissions and improving feed quality, while an important element – thermoregulation – is missing. However, it is thermoregulation that provides the biggest breakthrough in efficiency, and by covering all these elements in general, it is possible to achieve a 60 % reduction in total emissions without reducing (even significantly increasing) the productivity.

1.6. Challenges of the agricultural sector's progress towards climate neutrality

Rural areas often have economic potential, which is rarely fully realized. As clarified previously, energy efficiency trends in the agricultural sector also point to necessary improvements in the whole EU. However, the main problem is the large proportion of hard-to-reduce greenhouse gas (GHG) emission sources, which is the main characteristic of this sector [46]. Both in Europe and Latvia, the agricultural sector is one of the largest sectors producing GHG emissions (382.45 and 0.1 million tons of CO_2eq), with high potential for productivity and efficiency improvements [202].

As many of the resources used in agriculture are depletable, it is crucial to find methods to ensure their efficient management, sustainability, and availability in the future [203]. It is crucial to implement energy efficiency and resource efficiency measures without simultaneously reducing productivity [204]. However, these energy efficiency measures in the agricultural sector often require large investments in new technologies, and saving on factors such as lighting intensity, heat energy consumption, and the economy of various resources is not possible, as it could potentially threaten the existence of companies due to reduced or possibly even non-existent harvests. Agriculture is a sector subject to technological processes whose application has a direct impact on the production of competitive products with higher added value [205].

NECP's planned measures related to animal husbandry are to improve the manure management system for more efficient use of fertilizers, which is essential regarding both the plant yield and the environmental aspect; to implement manure fermentation biogas reactors, which have the potential to reduce GHG emissions to a minimum in large farms, ensuring efficient manure management and production of renewable energy and valuable fertilizer for crops; to improve animal feeding—various methods are known and used around the world for determining the digestibility of fodder, as well as for determining and analyzing the amount of gases released by animals. Balanced and appropriate feed affects the rate of N release from manure, which has a positive effect on the reduction of N_2O emissions. Meanwhile, improving feed quality increases feed digestibility and reduces CH_4 emissions. Thoughtful, sustainable management would improve the rural population and the well-being of the inhabitants; in addition, the fertility of the land would not be reduced, the yield of crops would be increased, and the demand for energy from external resources would be reduced. It would not only reduce the impact on the environment, but also promote the competitiveness of local companies in the market by reducing expenses. This produces products with higher added value, making full use of all available resources. However, unprofessionally adopted policies that focus only on specific agricultural sub-sectors or groups of companies may not only prevent these goals, but also even delay them. It should be considered that agriculture is a very complex system in which simple saving measures and knowledge are not enough, because various innovations and technologies are needed to achieve these savings and productivity [206].

Sub-sectors such as cereal and berry farming has been expanding in Latvia, while other sub-sectors are experiencing rather slow development or stagnating [47]. The total number of dairy farms in 2021 has decreased by 10 % compared to 2020, and the total number of dairy cows has decreased by 3%, bringing the number of registered dairy cows to 131 207 [47]; the density of farm animals in Latvia is one of the lowest in Europe [207]. The production of milk has almost reached the EU's average milk yield, which is an important indicator of livestock welfare [207]. Additionally, the value of primary production per hectare of agricultural land in Latvia is one of the lowest in the EU, despite good climatic conditions and available water resources [208].

Although the planned measures are theoretically very promising, there is a huge resistance among farmers, where the prevailing concern is about the inequality and destruction of business in the agricultural sector, and the inability to compete. Due to the complicated structure of the sector, it tends to be very difficult or even impossible to determine the real obstacles and mistakes that delay the progress of sustainable farming. To depict most vividly how problematic the implementation of energy efficiency and resource efficiency can be, animal husbandry will be emphasized, which we are forced to look at with special caution and responsibility, considering that it is not only about plant harvest, but also living creatures.

In animal husbandry, thermoregulation—heating, conditioning, lighting, and ventilation—is particularly important for animals kept indoors [209]. The quality of air, food, and water has the greatest impact directly on the health of animals, and therefore also on productivity, which is the most important indicator in animal husbandry [210].

Today, ranchers are increasingly using robots and algorithms in production to optimize their farm management decisions [211]. The development of technology creates a new automation system that provides smarter and more flexible work opportunities in animal husbandry [212]. These technologies provide livestock farmers with data-based insight into economic activity, which allows them to provide the necessary animal care and increase productivity and provides them an opportunity to manage the farm more easily.

One of the biggest consumers of electricity, next to lighting, is ventilation, which often accounts for at least a fifth of the barn's maintenance costs [213], so that harmful gases such as ammonia and carbon dioxide do not exceed their critical permissible concentrations [28]. Some solutions to increase efficiency is modern building construction or innovations such as green roofs and walls to reduce indoor temperatures [214]. The main goal is to successfully combine mechanical ventilation and thermal insulation with natural alternatives, and such engineering solutions help to reduce energy by up to 50 % [213], increasing milk productivity by at least 10–15 % [215]. The most important aspect is to pay attention to thermoregulation because it will result in higher animal productivity; if dairy cows suffer from overheating during summer for about 6–15 h a day, it can result in a loss of 3.5 l of milk per day due to heat stress. Often, if all resource saving and energy efficiency measures have been taken, it is important to start thinking directly about the possibilities of installing renewable energy sources on the farm.

Development has also taken place in feeding animals. Computer programs have been developed that cover each stage of feeding: feed preparation, mixing and dosing, and feed distribution. They make it easier to plan the rations needed by the animal and give the ability to supplement the feed with fatty substances. Efficient use of feed can reduce methane gas emissions as well as give the ability to obtain the biggest yield. Furthermore, a sensor has been created that reads the movement of the animal's jaw to determine whether it digests the food completely.

One of the biggest threats in animal farming is disease, as it can spread very quickly between animals. Sickness of an animal has an economic impact on the farm, so it is important to detect the disease in its first days. Doing so reduces the cost of treatment, reduces the mortality rate, and improves production efficiency. It is possible to determine the state of health of animals by their behavior, body condition, and food intake, so companies have created programs based on the acquisition and analysis of data parameters. To obtain data from the animal, sensors are installed on it—the task of which is to collect data about the animal's condition and pass it on to analysis points [216].

2. METHODOLOGY

To achieve the research objectives, several methods were used – carbon balance, sustainability SWOT analysis, multi-criteria analysis, TIMES model and system dynamics model. The methodology and results sections are reviewed sequentially.

2.1. Carbon balance method

A carbon balance was carried out to objectively quantify naturally or anthropogenically added or removed carbon dioxide from the atmosphere to determine the environmental impact of biogas production from specially grown maize silage [217]. Although the carbon balance method has been used so far, for example, to model the change of land use [218] or of forestry under various effects of forestry management methods [219], there are no studies that have developed carbon balances to determine the environmental impact of substrate selection in biogas production.

Although many authors have acknowledged that when analyzing biomass life cycle analysis, the range of results is quite wide [220] due to the differences in various factors and system boundaries [221], it is considered to be the best method for calculating GHG balance [222]. To better understand the system and the emissions to be considered in this case, a scheme was created, which can be seen in figure 2.1. The methodology was based on life cycle analysis, which included calculations of:

- emissions from maize silage cultivation due to tillage, mineral nitrogen fertilizers and fuel use in heavy machinery (both in the process of growing maize, in the process of preparing the substrate for biogas production, and in the process of incorporating digestate into the soil);
- emissions collected due to the photosynthesis process;
- emission leaks from biogas production process;
- emissions from the use of maize digestate fertilizer;
- emissions saved from the mineral fertilizer replacement with digestate;

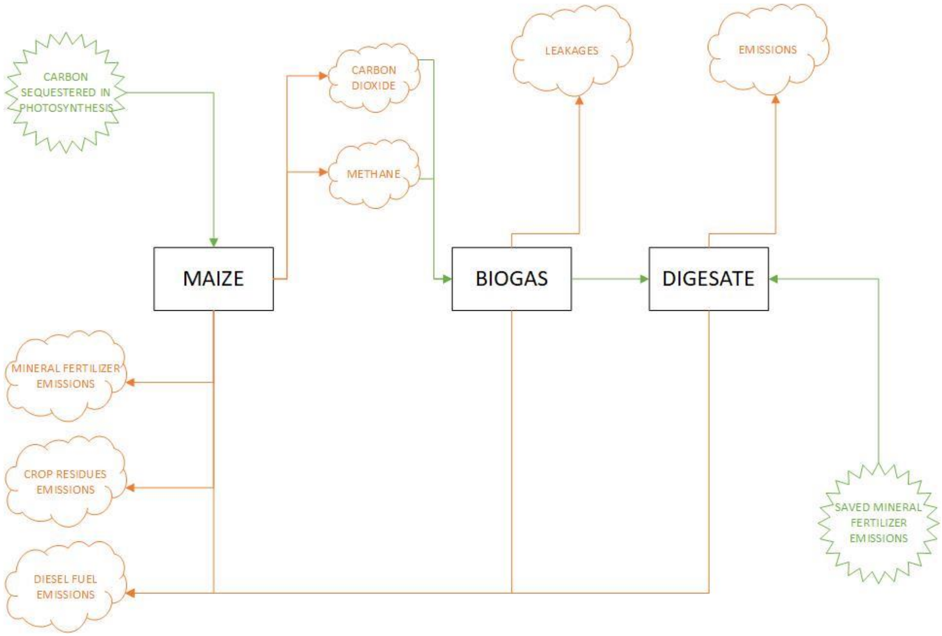


Fig. 2.1. Processes included in the calculation of carbon balance of biogas produced from specially grown maize.

To calculate fuel emissions, data were collected from an agricultural farm in Latvia and shown in Table 2.1. It is important to note that the results of the calculations may differ, if a more detailed calculation is made, considering factors such as soil consistency and the technologies used, the efficiency of tractors and other indicators. The more efficient the techniques and methods used, the lower the emissions from maize production process. First, the number of times specific tractor-tillage techniques that use diesel fuel and the tons of diesel fuel consumed per 1 ha of the activity by off-road vehicles and other machinery were collected to an indicator of how many tons of diesel needed per hectare and how many tons of diesel fuel are consumed per year to process 1 ha of biogas maize fields. In turn, knowing the area of land that was used to grow the biogas maize substrate in a given year, can provide an indicator of all year's fuel consumption for biogas maize cultivation per ha.

Table 2.1.

Diesel fuel consumption for the production of maize for biogas production

	Times	Fuel needed, t/ha at a time	Fuel needed, t/ha	Area, ha	Fuel consumed over the area, t/year
Ploughing	1	0.025	0.025	5382	134.335
Shuffle	1	0.008	0.008		44.778
Cultivation	1	0.007	0.007		40.300
Sowing	1	0.007	0.007		35.823
Plant protection + microelements	3	0.006	0.017		94.034
Shredding	1	0.029	0.029		156.724

Fertilizer application	3	0.004	0.012		67.167
Transportation field-farm	1	0.016	0.016		85.437
Compression	1	0.031	0.031		167.918
Picking from the pit, pouring, dumping	1	0.017	0.017		89.556
Incorporation of digestate into soil	1	0.015	0.015		80.601
In total	-	-	0.185		996.674

By finding out the lowest combustion heat of diesel fuel, it is possible to obtain consumed energy for field treatment [133]. But, knowing the energy consumed in the process in field cultivation as well as using the emission factors of the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines, it is possible to obtain the result in terms of tons of emissions from the use of fuel [134]. By determining the annual emissions, indicators – emissions from the processing of 1 ha of maize used for biogas production – are calculated.

During the special cultivation of maize, fuel is not the only source of emissions, it is also caused by the incorporation of crop residues into the soil, as well as the use of nitrogen, therefore the Tier 1 methodology from the 2006 IPCC guidelines was used to calculate nitrous oxide emissions from managed soils [133]. For direct nitrous oxide emissions from agricultural soils, the following equation was used:

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

where:

N_2O –N –N_2O emissions in units of nitrogen (direct N_2O emissions from treated soils, kg N_2O–N year^{-1})

F_{SN} − *the amount of nitrogen in the fertilizer applied to the soil* $(\frac{kgN}{year})$

F_{CR} – N amount of maize residues entering the soil on an annual basis (above and below ground)

EF - N_2O emission factor from N input, kg N_2O–N kg^{-1} N (input = 0,01)

The following equation was used to report *kg N_2O–N emissions to N_2O emissions:*

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

One of the calculation parameters for estimating the direct nitrogen oxide emissions from the use of N in managed soils is the amount of pure nitrogen fertilizers per year. Data on the required inorganic fertilizers used in soils are taken from A. Kārkliņš book "Calculation methods and standards for the use of soil treatment and fertilizers", which states that a maize yield of 31.8 t/ha requires 0.1 t/ha N fertilizer [133].

Yield N per year is calculated on the Tier 1 methodology of the 2006 IPCC Guidelines:

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

where:

$Yield$ − *harvested maize yield (kg fresh maize yield/ha)*

DRY – dry matter part of harvested maize (kg dry matter /kg fresh matter)

$Frac_{Renew}$ *– total area of maize*

Area – the total part of the area harvested for maize (ha/year)

RAG – terrestrial, surface residue solids (AGDM) and maize harvest (Crop), kg dry matter (kg dry matter)-1,

N_{AG} *– N surface plant residue content in maize (kg N/kg dry matter)*

R_{BG} *– ratio of underground residues to maize yield (kg dry fraction/kg dry fraction)*

R_{BG} *can be calculated by multiplying RBG-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) (0.007)* [223].

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

$$R_{AG} = AGDM * 1000/Crop, \tag{2.4.}$$

as well as an additional equation to estimate terrestrial surface solids AGDM (Mg/ha):

$$AGDM = (Crop/1000) * slope + intercept. \text{ [133]} \tag{2.5.}$$

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

$$Crop = Yield\ Fresh * DRY, \tag{2.6.}$$

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)$^{-1}$[133]

Although the use of digestate in field fertilization reduces emissions compared to synthetic fertilizers, digestion of soil with digestate also generates greenhouse gas emissions [224]. The results of analyzes obtained from the farm “X” producing biogas from maize indicate that the N content of the digestate fertilizer is on average 3.8 kg/t. By knowing the N content of the digestate and the tons of digestate obtained, digestate fertilization emissions were calculated by the 2006 IPCC guidelines [134].

When looking at emissions from the biogas production process, it should be considered that although biogas is produced from maize, which is a renewable resource and recovers the carbon emissions that the plant has absorbed during its growth process, emissions from the biogas production process are considered. Based on the scientific article emission leakages account for 1 % of biogas losses in biogas production, which includes both the 52 % methane in it and the remaining 48 %, which is assumed to be carbon dioxide [225].

Although GHG emissions result from field cultivation during maize cultivation, maize growth involves photosynthetic processes that sequester CO_2 from the atmosphere [226]. In order to calculate the amount of CO_2 captured in a year in a certain area of biogas maize, the amount of dry matter is multiplied by the CO_2 sequestration factor [32].

All variations in the amplitude of losses are summarized and presented as an average.

2.2. Sustainability SWOT analysis

The sustainability SWOT analysis, where Strengths, Weaknesses, Opportunities, Threats are analyzed, is a new twist on the familiar SWOT, where much more can be incorporated than environmental issues [227]. It is a very simple method to be effectively used not only for companies, resource planning, but also for strategy prioritization at industrial and policy level [227],[228]. It is meant to drive collaboration on environmental challenges, possible risks, and opportunities, which otherwise may go unnoticed.

This part of research is a result of a literature review, mainly analyzing reports, legislation, scientific articles that were identified as a relevant material to provide understanding of the recent evaluation of Latvia's biogas sector. The search was performed mainly using Google, ScienceDirect, Web of Science, Google Schoolar. A combination of the following search requirements were used in the process of finding relevant information and articles: "biogas", "biomethane", "Latvia", "Green Deal", "Paris Agreement", "European Union", "Agriculture", "greenhouse gas", "plant", "energy crops", "cogeneration", "upgrading", "feedstock", "legislation", "infrastructure", "gas", "manure", "renewable", "strategy", "production", "energy", "fuel", "National Industrial Policy", "guidelines", "National Energy and Climate Plan", "economic", "efficiency", "economic", "technical". The following three conditions were applied:

Priority was given to the most recent articles, when selecting sources of information;

- special attention was given to select papers for the relevance, for example, national plans, technological and economic reports for Latvia's energy, biogas sector, journal articles to look objectively at the most pressing issues and developments of the last 20 years;
- scientific papers published in peer-reviewed journals in English.

It studies the development of the Latvian biogas industry, which is especially relevant and interesting due to its instability and rapid variability. The analysis sheds light on the economic, environmental, political, and social dynamics through the application of Sustainability SWOT (sSWOT) method.

Based on the obtained literature review, a table was created accordingly (presented in the results section), in which the strengths, weaknesses, opportunities and threats were defined [229].

2.3. Multi – Criteria Analysis

The TOPSIS method is one of the methods that allows to determine the exact value of criteria to compare different units with great success. The TOPSIS method used in this work to make a decision was "The classical TOPSIS method for a single decision maker". The TOPSIS method is chosen for this research, because it allows compromises between criteria, where a poor result on one criterion can be offset by a good result on another criterion, thus providing more realistic modeling than methods that include or exclude alternative solutions due to strict constraints [230]. Unlike other methods, in the TOPSIS method the optimization (max or min) for the desired outcome is determined for each criterion and it assigns a value to each alternative [231].

During the first step of the research, data collection and analysis, including review of scientific literature, initial data and regulations were done. Based on results of the first step of study, indicators (technical, environmental, and economic) used for multicriteria decision making process, were identified, and selected. During the next step values of indicators were set and after the normalization and weighting of indicators, rating, and evaluation conducted. The methodological algorithm of the research is shown in Figure 2.2.

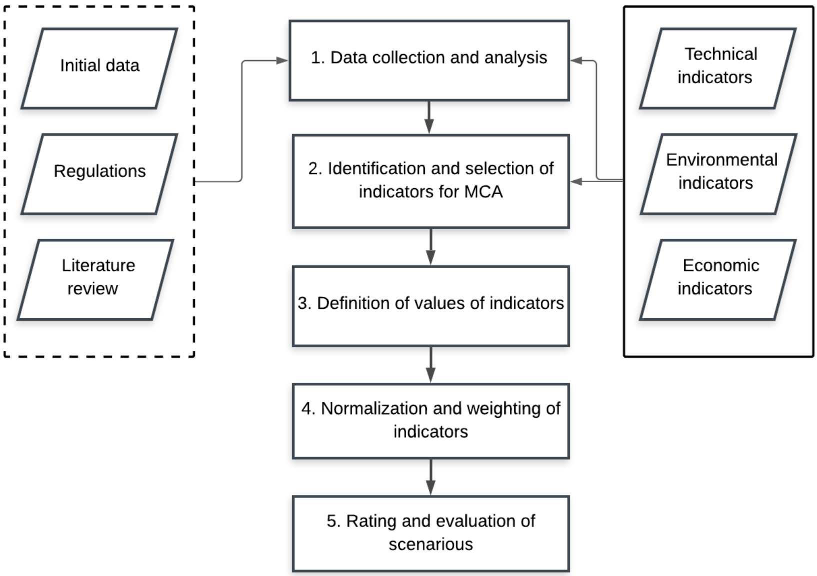


Fig. 2.2. Concept of the methodology.

The TOPSIS method is based on 7 main steps:

- demonstrate a performance matrix;
- normalize the decision matrix;
- calculate the weighted normalized decision matrix;
- determine the positive ideal and negative ideal solutions;
- calculate the separation measures;
- calculate the relative closeness to the ideal solution;
- rank the preference order. [232]

In the first step the decision matrix (X = (x_{ij})) must be constructed, as well as the weight of criteria (W= $[w_1, w_2, w_3]$) must be determined, where

$$W = w_1 + w_2 + w_3 = 100\%, \quad (2.7.)$$

Criteria of the functions can be:

- Benefit functions, where more is better (the higher the numerical value the closer to the ideal);
- Cost functions, where less is better (the lower the numerical value the closer to the ideal) [233].

In the second step all criterions must be maximized. The minimizing criterions must be converted. Before normalization, the numerical values of all criteria are subtracted from the worst-case scenario values in the determination matrix and a new matrix is created, while the newly acquired matrix yields the normalized value by the formula:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \tag{2.8.}$$

In the third step the weighted normalized decision matrix values (v_{ij}) must be calculated by multiplying the normalized matrix values with the weight of the criterions by formula:

$$v_{ij} = w_j * n_j, \tag{2.9.}$$

In the next step the positive ideal solutions (extreme performance on each criterion) and negative ideal solutions (reverse extreme performance on each criterion) must be determined [233].

The positive ideal solution A^+ has the form:

$$(A^+ = \max v_{ij} \mid j \in I), (A^+ = \min v_{ij} \mid |j \in J)), \tag{2.10.}$$

but negative ideal solution A^- has the form:

$$(A^- = \min v_{ij} | \, j \in I), A^- = \max v_{ij} \mid j \in I), \tag{2.11.}$$

where I is associated with benefit criteria and J with the cost criteria [233]. When the positive and negative ideal solutions are determined, the separation measures from the positive and negative ideal solutions must be calculated:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}, \text{ i} = 1, 2, \ldots, \text{m}, \tag{2.12.}$$

from the positive ideal solution, but

$$d_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}, \text{ i} = 1, 2, \ldots, \text{m}, \tag{2.13.}$$

from the negative ideal solution. [233] After finding the d_i^+ and d_i^- values, the relative closeness of the i-th alternative A_j with respect to A^+ is defined as:

$$R_i = \frac{d_i^-}{d_i^+ + d_i^-}, \tag{2.14.}$$

where i = 1, 2, …., m. [233]

As a final step a set of alternatives now are ranked by the descending order of the value of R_i [233].

2.3.1. MCA to find the best bioresources for biogas production

Multi-criteria analysis was carried out to determine Latvia's biogas sector potential – to predict the best feedstock depending on resources available in the country, which of the substrates for biogas production has the highest potential and sustainability. The following raw materials were analyzed in this multi-criteria analysis: cattle manure, swine manure, poultry manure, sewage sludge, organic waste, wood, straw, maize silage. This research compares 8 substrates with 3 different parameters – economic feasibility, environmental friendliness, and technological aspect – efficiency. To evaluate, which parameter is the most important in the selection of raw materials, industry experts voted and determined the percentage of each parameter weight.

The year of 2017 was used for data collection, and this multi-criteria analysis does not consider 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 multicriteria analysis, the efficiency of different feedstocks in terms of yield, how many cubic meters of biogas can be obtained from a ton of a given feedstock was analyzed.

According to the literature review, the efficiency of cattle manure for biogas production ranges from 25 – 45 m^3/t depending on whether it is liquid (liquid manure has the lowest efficiency) or solid mass, and for pigs from 28 – 60 m^3/t. Similarly values were obtained for biogas extraction efficiency from wood and straw, where the efficiency of the trees ranges from 25 – 46 m^3/t, depending on the type of wood – from raw birch it is possible to obtain 25 m^3/t of biogas, but from treated spruce 46 m^3/t [234]. The biggest yield of biogas is possible to produce from straw 180–200 m^3/t, depending on the type of treatment and from sewage sludge, where the yield is 218 m^3/t [234],[235]. The efficiency of these raw materials was determined as an average value and summarized in the Table 2.5 for the case of Latvia.

To determine the importance of using a particular substrate in the production of biogas, data was collected on how much emissions it could eliminate, thus approximating the proportion of their availability and importance, and environmental impact depending on how much this material is produced in one year and its emission factor. To calculate objectively the amount of emissions that could potentially be avoided (both nitrous oxide and methane), emissions were compared to carbon dioxide equivalents and added up. 1 kg of nitrous oxide was calculated as 298 kg carbon dioxide, while 1 kg of methane was calculated as 25 kg carbon dioxide [236].

In total 3 main criteria were considered:

- substrate efficiency;
- environmental friendliness;
- economic feasibility.

To determine, which is the most important criteria, a survey and a vote was carried out between different experts in the field of biogas production. As a result, of the 100 %, experts voted that the most important criteria were climate friendliness with 35 % and economic justification with 35 % as the deciding factors. Only 5 % less important was the technological aspect responsible for substrate efficiency.

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

Table 2.2.

Characteristics of livestock population and emissions from manure management in 2017 [237]

	Mature dairy cattle	Other mature cattle	Growing cattle	Swine	Poultry
Population size, thousands	150.4	77.5	177.9	320.6	4943.8
CH_4 emissions, kt	2.60	0.15	0.20	0.79	0.07
CH_4 emissions, $ktCO_2eq$	65.00	3.75	5.00	19.75	1.75
N_2O emissions, kt	0.11	0.01	0.02	0.02	0.01
N_2O emissions, $ktCO_2eq$	32.78	2.98	5.96	5.96	2.98
Emissions in total, $ktCO_2eq$	97.78	6.73	10.96	25.71	4.73

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

Table 2.3.

Wastewater dry content and emissions in 2017 [237]

	Total organic product, ktDC/year	CH_4 emissions, kt	CH_4 emissions as CO_2 equivalent, kt	N_2Oemission, kt	N_2O emissions as CO_2 equivalent, kt	In total, $ktCO_2$ equivalent
Domestic wastewater	42.71	3.16	79.00	0.11	32.78	111.78
Industrial wastewater	13.51	0.07	1.75	0.00	0.00	1.75

Domestic and industrial wastewater's emissions are calculated and showed in Table 2.3. In Table 2.4 these emissions are summed up for the multi-criteria analysis. Their total emissions as CO_2 equivalent is 113.53 kt/year.

Table 2.4.

Annual solid waste emissions in 2017 at the waste disposal sites [237]

	Annual waste, kt	**CH_4 emissions, kt**	**CH_4 emissions, $ktCO_2eq$**
Managed waste disposal sites	230.62	10.55	263.75
Unmanaged waste disposal sites	-	5.59	139.75

Methane emissions from solid waste are shown in the Table 2.4. In total both managed and unmanaged waste disposal sites emit 403.50 $ktCO_2eq$ per year, because of the organic waste in disposal sites. This problem could be partly overcome by changing the shopping and eating habits of people, thus reducing the amount of food thrown away. However, such a shift in people's attention takes a long time and, until it is successful, this "waste" can be used effectively in biogas production, because it is creating the biggest emissions of all analyzed raw materials in this work.

Whereas in Latvia biogas is used as biomass in combustion processes to generate heat in the boiler houses, and it can be done by burning straw too, and theoretically the emission of their combustion is 0, it is shown as a climate neutral substrate to be used in biogas production. Latvia's sustainability development strategy until 2030 set that in the future renovation of existing boiler houses and new cogeneration plants, the use of local energy sources, which include both wood and straw, is mandatory [238]. Also, the exact residues are not known and whether such lignocellulosic waste is very topical in Latvia at all, because many furniture manufacturing and woodworking companies use these wood waste for heat production in their own companies for their own needs.

The literature review in this work already described the reason why Latvia's goal is to move away from the use of maize in biogas production. The main reason is that maize is grown in Latvia specifically for biogas production, rather than using corn waste/residues only. It means that although it is renewable energy source, fossil fuels are used in off-road vehicles and other machinery, as well as fertilizers for field treatment. To calculate the emissions from maize cultivation, a study was parallelly carried out to collect information on the 3 main factors for maize cultivation:

- emissions from diesel fuel use in agricultural machinery;
- emissions from mineral fertilizer treatment;
- emissions from crop residues.

As a result, an indicator was obtained that 1.61 tCO_2eq emissions per ha was generated for the cultivation of maize silage to produce biogas in 2017.

These emission values from the biogas maize fields were used as indicators for the calculation of maize growing emissions in Latvia. According to data provided by the Central Statistical Bureau, in 2017, 5382 ha of land were used in Latvia to produce 170 964 t of biogas maize. It means that in Latvia biogas maize production yield has reached 31.8 t/ha in 2017. By multiplying the emissions produced per biogas maize cultivation tCO_2equivalent/ha with the

Latvia's cultivated land area of maize, there were about 3448.6 tCO_2eq produced in Latvia from biogas maize production in 2017.

Although biogas production indirectly improves the financial stability of the state and reduces the need for impregnated energy resources, biogas plants have to make huge investments and their operation and maintenance costs are high, regardless of the size of the plant, because large plants are even more profitable both in terms of investment and operation [239]. As the Latvia's University of Agriculture has carried out a research and calculations that used fresh manure at biogas plants practically does not produce enough methane or nitrogen, it is necessary to mix manure with energy crops to increase the amount of biogas produced, thus reducing costs [239]. Although cultivation of biogas maize is a costly measure, as both fuel use in off-road vehicles and field fertilizer treatment entail costs, as Latvia does not have a unified organic manure collection system that could partially solve the admixture substrate to manure, it is more profitable to use maize than livestock manure only. Already now in Latvia biogas is collected from organic waste dumps and wastewater as their efficiency is very high and as shown in Table 2.5 they do not require additional raw materials such as biogas from livestock manure only.

To determine, which feedstock is the most economically advantageous for biogas production, information on feedstock prices was collected. The largest Latvian advertisement portal ss.com was used to find out the price of manure, as well as straw and corn, which showed that on average beef manure is sold for 3 €/t , poultry manure for 2 €/t, but pig manure is charged a very symbolic price of about 1 €/t [240]. Straw bales were found to weigh an average of 0.45 t, but 1 bale is sold for an average of 7 €/piece, while 1 t of corn silage costs 50 € [240]. By making the calculations, 1 t of straw costs 15.56 €/t. A symbolic price of 1 €/t was adopted for wastewater. The price of organic waste was determined by obtaining information on the website of the largest landfill site in Latvia, where it is offered to deliver the organic waste to landfill for 60.81 €/t +VAT. It means that the cost of transferring the waste in total with VAT costs is 73.58 €/t [241]. As the transfer of this waste costs a certain amount of money, its use at the on-farm biogas plant means a reduction in costs and for that reason the cost of organic waste is shown with a minus sign in Table 2.5. According to surveys of the biggest woodchip suppliers, its price is currently 12 €/m^3. Given that 1 t of woodchips is equivalent to 3.5 m^3 of woodchips, the price per t is assumed to be 42 €.

Table 2.5.

Calculation of economic justification for each substrate

	Efficiency (yield of biogas), m^3/t	**Price of the feedstock, €/t**	**Economical factor, €/m3 biogas**
Cattle manure	35	3.00	0.09
Pig manure	44	1.00	0.02
Poultry manure	80	2.00	0.03
Sewage sludge	218	1.00	0.01
Organic waste	100	-73.58	-0.74
Wood	35.5	42.00	1.18

Straw	190	15.56	0.08
Maize silage	202	45.00	0.25

Summarizing the information obtained on the biogas efficiency of the feedstocks as well as the price per t of the feedstock, it is possible to obtain an economic justification for each substrate. To obtain the cost of producing 1 m^3 of biogas from a given substrate, the substrate price was divided by the substrate efficiency. As a result, the 3 main criteria identified as determinants of biogas substrate selection were summarized in Table 2.6 for objective comparison.

Table 2.6.

Multi-criteria analysis values

	Efficiency (yield of biogas), m^3/t	**Environmentally friendly (emissions to be collected in Latvia), kt CO_2eq/year**	**Economical factor, €/m3 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 the information about the substrates, the highest efficiency of biogas production is in the production of biogas from sewage sludge as well as maize silage. Straw does not lag behind in the productivity of maize silage biogas. The lowest efficiency is observed in cattle manure and wood, with average efficiency values almost equal. Only slightly higher efficiency is observed in pig manure.

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

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

To determine objectively the best raw material for biogas production, the TOPSIS model was developed, and the results are presented in the relevant result section.

2.3.2. MCA to find a sustainable way for the use of biogas

Although biogas production is particularly suitable for Latvia, because agriculture in Latvia accounts for 24,6 % of total GHGs, ranking as the 2nd largest GHG emitting sector, since 2016 [242], when 56 biogas plants were in operation, 7 plants have ceased their operations by 2020, moreover, in 2020 at least 5-6 more biogas plants are planned to stop operating. At the same time transport sector is the biggest GHG emitting sector in Latvia and although EU member states must ensure 10 % of renewable energy consumption in transport sector by 2020, when in 2018 its share was only 4.7 %, biogas is not used in the transport sector at all [18]. All of the 11 million m^3 of biogas produced in 2018 is being combusted in cogeneration plants (installed capacity 61.22 MW with 80 % workload) due to its high efficiency (90 % in total: 50 % thermal and 40 % electrical) [19] and used in agriculture or similar sectors as heat and electricity [18]. Although there is great potential in biogas purifying to biomethane, it does not reach the maximum efficiency, since the raw gas contains approximately 65 % CH_4 and 35 % CO_2 of the volume, so acquisition of biomethane is measurable on average 63 % [20], therefore upgrading of biomethane, for example by hydrogen methanation, should be done, which allows to increase CH_4 output of the biogas system by 70 % [244].

One of the main policy directions set out in the current policy planning document to achieve the goal set in a particular policy planning document is the use of biogas resources and promotion of the production of biogas and biomethane and the use of biomethane and it is implemented in all target farms to produce biogas and purify to biomethane, which is also determined with a relevant legal acts to ensure the installation of biogas treatment plants within the EU structural funds or other sources of financing in the period after 2021 [49],[17].

The transition from fossil fuels to biomethane could be one of the main ways of meeting the transport sector's goals. It could not only economically benefit farmers, who would save on fertilizer costs, but also reduce GHG emissions in manufacturing industry by not making these mineral fertilizers and using the digestate instead [22].

Given that the largest consumption sector in final energy consumption is transport, as well as the fact that the transport sector is the largest source of GHG emissions, it would be important to set the lowest possible excise tax rate for biomethane and biofuels from 2022, evaluating the possibility to differentiate the reduced rates for first generation biogas [17].

That's why the focus in this research is on agricultural biogas, which can be used for 2 purposes in energy sector: (a) combusted in CHP systems, as well as electricity used for auto transport; (b) purified to biomethane and used for auto transport (see Figure 2.3). The methodology is demonstrated on Latvia as a case study.

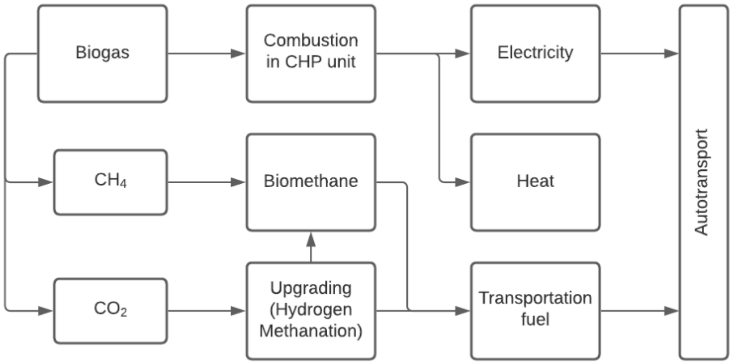


Fig. 2.3. Biogas application.

To achieve the goal of this research – evaluate the sustainability of biogas application in energy sector, a multicriteria analysis has been used. For the assessment of competing scenarios, indicators for the technical, environmental, and economic dimensions were developed. Mentioned indicators were established after literature review and gathering the opinion of experts in this area. Six indicators were used to analyse biogas application options in energy sector (see Table 2.7).

Table 2.7.

Indicators used for the assessment of biogas application scenarios

Dimension	Indicator	Unit	Preferable outcome	Weight of the indicator, %
Technical	Efficiency of the whole system	%	Max	10
	Efficiency gains for the transport sector	%	Max	20
	Energy produced for transport sector	MWh	Max	10
Environmental	Reduced GHG emissions	$ktCO_2eq$	Max	30
Economic	Costs	€/MW	Min	25
Economic	External Costs	€/MW	Min	5

These six criteria from three dimensions were used for the assessment of analysed scenarios. Criteria weights were determined by experts in the field. Values for indicators were obtained both from the literature and Latvian Biogas Association.

The inventory submitted in 2018 indicates that in 2016 the emissions of the energy sector were 7239.16 $ktCO_2eq$, thus, if the transport sector is responsible for 44.2 % of emissions from the energy sector [246], it equals to 3199.71 $ktCO_2eq$.

As the transport sector also include emissions from air traffic, emissions from diesel fuel were also considered separately in this work, and in 2016 a total of 753 000 t was used in transport sector, but 693 000 t or 832 932 692 l was used in auto transport [247]. If 1 l of diesel equals 1 m^3 of biomethane, which is 10 kWh in terms of energy [248], it is possible to calculate the potential impact on the environment if biomethane were produced from all currently produced biogas, as well as compare the impact if all electricity already produced in cogeneration plants from biogas were used in electric cars.

By finding out the lowest combustion heat of diesel fuel (0.043 TJ/t) [249], it is possible to obtain process energy for field treatment [250]. Knowing the energy consumed in the process in field cultivation as well as using the emission factors of the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines:

- CO_2 emission factor is 74.74849 t/TJ = 0.269 t/MWh;
- CH_4 emission factor is 0.00415 t/TJ = 0.015 kgCO_2/MWh;
- N_2O emission factor is 0.0286 t/TJ = 0.103 kgCO_2/MWh;

it is possible to obtain the result in terms of tons of emissions from the use of fuel [46].

Considering the total installed electrical capacity of all stations in 2018, which, according to the Latvian Biogas Association board member, was 61.22 MW, while average workload was 80 %, and Biogas Association Member's given data of produced electricity, using biogas, in cogeneration plants produced 347.94 GWh of electricity, which could be used for electric cars as a climate neutral or negative fuel in transport sector.

As the mandatory target for renewable energy in transport by 2030 is 14 % [46], with the use of already produced biogas in cogeneration plants, while the use of electricity from cogeneration in transport, it would already provide 4.18 % share of renewable energy in road transport sector's diesel fuel use and 4.13 % reduction of whole transport sector emissions according to 2016 transport data.

According to the Central Statistical Bureau, 11 million m^3 of biogas was produced. If all this biogas were used for methane production, 6.93 million m^3 of biomethane with 63 % efficiency would be produced while an additional methane would be produced during hydrogen methanation process from the rest of the biogas, which contains of 35 % carbon dioxide, and could be used in the transport sector. Biological hydrogen methanation could not only increase the biomethane yield, but also lower the costs for biogas upgrading to natural gas quality [27]. Efficiency of the process in a cogeneration plant right after the methanation is 30-45 % (37.5 % on average) [27], which means that if 4.07 million m^3 carbon dioxide is produced, then with biological hydrogen methanation digesters it is possible to maintain 1.83 million m^3 of methane. Knowing that 1 l of diesel equals 1 m^3 of biomethane, which is 10 kWh in terms of energy [28], the potential impact on the environment would be 1.83 million l of saved diesel fuel, which means 18.3 GWh.

Values for economic indicators were obtained from literature and represent capital costs for biogas production and cogeneration in CHP unit and biogas production and upgrading to biomethane.

Multicriteria analysis method TOPSIS was used for the determination of the best scenario for biogas application in energy transport. Normalized and weighted decision-making matrix is showed in Table 2.8.

Table 2.8.

Normalized and weighted decision-making matrix

Indicators	Technical indicators			Environmental indicator	Economic indicator
	Efficiency of the whole system	Efficiency gains for the transport sector	Energy produced for transport sector	Reduced GHG emissions	Costs, €/MW
Scenario 1	0.076	0.093	0.098	0.291	0.260
Scenario 2	0.065	0.177	0.021	0.073	0.150

2.3.3. MCA to find the most suitable carbon farming solutions

The goal of this research – to identify carbon farming solutions for Latvian conditions and determine their importance in reducing GHG emissions. It compares 6 carbon farming options with 5 different parameters that were considered – 1 for economic feasibility, 2 for environmental friendliness and 2 for technological aspects – opportunities for the amplitude of methods implementation in real life, and they were weighted equally. To evaluate, which parameter is the most important in the selection of raw materials, industry experts voted and determined the percentage of each parameter. The methodological algorithm was applied on case study of Latvia, but it can be used for a variety of studies that need to find the best solution, depending on these criteria [251].

As one of the criteria for the TOPSIS analysis, the area allocated for this process already in Latvia without making any improvements or expansions was accepted. Also, the potential area is determined to find out the possible potential of the carbon farming methods not only in existing territories for these processes, but in the future, expanding the management of wider territories with sustainable practices. Since agricultural data in Latvia is relatively rarely updated, the used areas of 2016, indicated in the statistical databases, were accepted. Since the data on the extent of capture by soils application in the territory in Latvia is not known, the area allocated for it is currently accepted as the entire area used for farming, since the scope of application of this practice is very wide, but it has a huge potential for improvement at the same time. The areas required to produce biogas and biomethane were calculated if biogas was 100 % produced from the manure of agricultural animals currently present in Latvia, considering the area needed for pastures, as well as the area needed to produce the necessary food for these animals. Expansion of biogas and biomethane areas is not accepted because biogas and biomethane are products produced from a waste product and not as a primary product, therefore the development of this method will not be a determining factor to increase the number of farm animals in enterprises. In order to roughly determine the currently used area for biogas/biomethane production, the amount of energy produced in 2016 from biogas obtained in Latvia was determined [252] and taking into account how much yield can be obtained from 1 t of the respective type of manure [253], it was calculated that only 16.2 % of the manure resource available in Latvia is used. Accordingly, the currently theoretically used territory has been equated to the amount of biogas production. The potential expansion site for such practices as agroforestry and perennial plants is assumed to be the unmanaged Latvian scrubland.

One of the most important criteria for the development of these methods is the ability to attract the budget, because in practice, the introduction of new methods very often leads to financial losses for the farmer in the first years of transition, which is a possible determining factor why farmers choose to work with the previous methods, fearing to accept the risk. Therefore, to determine the available budget, the information was taken from Latvian Common Agriculture Policy (CAP) Strategic Plan 2023–2027 and information of Cohesion funds for Biomethane development.

As another important criterion, the amount of GHG emission sequestration in kilotons within one year of each method in the currently allocated areas was adopted. Since there is no exact data on how much emission occurs in these processes/sectors, the calculations were made based on assumptions from scientific publications. By improving and obtaining more accurate data on the agricultural sector of Latvia, this calculation should be improved by replacing assumption calculations with real data.

Since zero tillage predicts a 41 % emission reduction, while minimal tillage 26 % compared to conventional [140], data from conventional maize cultivation were used to calculate the estimated annual CO_2eq reduction [254]. The current potential of biogas and biomethane is calculated by considering IPCC Default GHG emission factors and average N excretion per head of animal per year. However, it should be taken into account that the real emission reduction would be much higher, because this calculation takes into account only those emissions that are prevented by managing agricultural animal manure, while if the calculation were done differently - not according to the usable area, where the reduction of GHG emissions depends in the most direct way on the territory to be used, but on the possible consumption of biogas/biomethane in Latvia, if the use of natural gas and fossils were completely replaced by biogas and/or biomethane (according to the potential amount that can be obtained, it is possible to make sure that this is a realistically achievable goal in the case of Latvia). Using Central Statistical Bureau data, which indicates that in 2016, natural gas consumption was 1371 m^3 [255], and EPA calculator [256], it is calculated that in 2016, 29 397 t of CO_2eq were generated due to the consumption of natural gas, which means that if biogas were used, emissions would not only be prevented by 100 %, but they would still be negative, as the use of biogas achieves a 240 % reduction in emissions compared to fossil resources [257] and 64 % compared to the natural gas in energy [170], while for biomethane 202 % to fossil fuel use in transport [257].

Accepting the application of willow biochar in the entire area of agricultural arable land in the current territories, as well as knowing that Willow biochar could compensate 7.7 % of annual agricultural greenhouse gas emissions [258], however, in 2018, soil cultivation in Latvia generated 1547.4 ktCO_2eq emissions [259], which was the largest sub-sector of GHG emissions in the agricultural sector in terms of emissions. The possibilities of sequestration could be as much as 119 ktCO_2eq per year, but it should be noted that this calculation is idealized without in-depth research on those areas where such application of willow biochar would not be desirable. However, considering the wide range of capture by soil methods, we accept it as an example calculation for all agricultural lands, which would be possible to achieve in the entire territory. Perennial plants can sequester about 3.6 tCO_2/ha/y [260] and knowing the currently used territory, the positive impact of the perennial plant on the environment can be calculated.

By calculating how much it would be possible to potentially sequester GHG emissions using all the resources available for the specific method, it is possible to see how big the opportunities for reducing emissions are provided by the implementation of positive agricultural practices. In this calculation, only those emissions that can be prevented because of manure management are considered in the biogas and biomethane potential. It does not include the emission reductions that would result from using digestate as fertilizer, so it should be noted that the true benefit would be much higher.

All values for TOPSIS indicators for the research are shown at Table 2.9.

Table 2.9.

Values for TOPSIS indicators

CF method	Area 2020.gads, ha	Potential area, ha	Budget, €	GHG emission sequestration in the existing areas allocated for this measure, $ktCO_2eq$/year	Potential GHG emission sequestration, $ktCO_2eq$/year
Zero tillage	12 818 [261]	370 000	5 550 000 [168]	8.2	595.0
Minimal tillage	68 388 [261]	370 000	5 550 000 [168]	27.9	377.3
Biogas	180 216.1	1 112 445	0	61.6	380.1
Capture by soils	2 285 477 [262]	2 285 477	16 688 447.8 [168]	119.2	119.2
Perennial plants	28 827 [262]	103 829	15 520 000 [168]	103.8	373.8
Biomethane	180 216.1	1 112 445	61 000 000 [263],[264]	61.6	380.1
Agroforestry	0	103 829 [262]	4 055 000 [168]	0	37.4

2.4. Energy efficiency measurement

The methodology was based on the IPCC guidelines, written in 2017–2018. The year 2005 was compared to 2015 to see the increase in emissions in the agricultural sector. The following methods, guidelines, and manuals were used in this research: IPCC Guidelines, Latvian Inventory Report on GHG Emissions, and manual 'Guide for Farmers to calculate GHG at farm level and measures to reduce it'. Analysis of indicators and comparison of agricultural enterprises will be carried out, and a methodology that can be applied at a certain level will be developed.

To achieve the goal of this research, an algorithm of methodology has been developed (Fig. 2.4). It is divided into eight stages, showing the advisable actions on each level – (1) evaluation of data on GHG emissions, (2) analysis of data on the national, (3) sectoral, or (4) company level, (5) analysis of the data on energy consumption, (6) comparison of the companies, (7) improvement measures are proposed, and (8) energy efficiency measures are defined. The algorithm's first part is oriented toward identifying and analyzing the current situation. Still, the second part is identifying future perspectives, searching for possibilities, and implementing practical solutions to promote development.

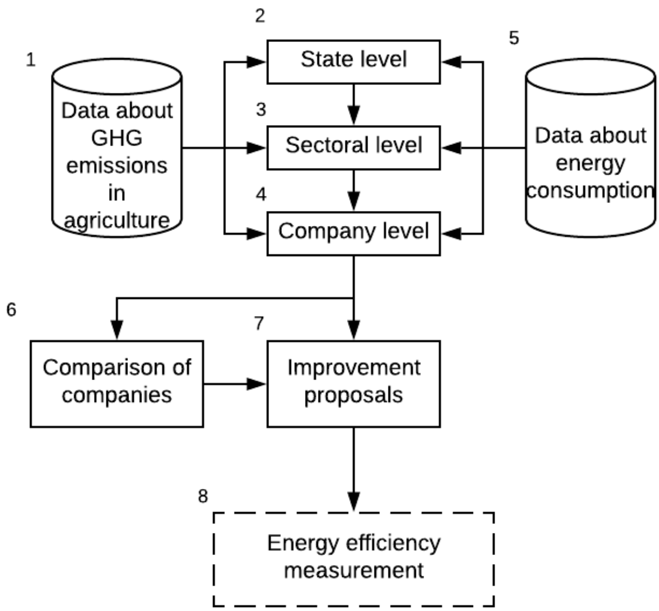


Fig. 2.4. Scheme of the methodology.

As it is seen on the scheme, the methodology includes eight modules, of which three are the main ones: state level (2), sectoral level (3), and company level (4). From stages 1 to 5, data collection and publicly available data are analyzed using data analysis methods. Data are compared in stages 6 to 8, and GHG emissions and energy reduction measures are proposed. These measures are also called energy efficiency measures.

Each year, every country in the European Union must submit an inventory report on GHG emissions developed by the IPCC guidelines related to the UN Framework Convention on Climate Change.

The inventory report includes direct and indirect GHG emissions from all sectors in the country, which are expressed in CO_2 equivalent. In the report submitted in 2017, GHG emissions were calculated for the timeframe starting with 1990 until 2015, considering the global warming potential coefficients for a one-hundred-year period.

In the Convention reporting guidelines, GHG emissions were compiled for such areas or sectors as energetics, industry and product manufacture, agriculture, land cultivation, land-use change method and forestry, and waste management.

The following subsection compares GHG emissions in CO_2 equivalent for 2005 and 2015. In the case study, data were taken from Latvia's inventory report about GHG emissions in the agricultural sector.

As the Inventory report divides the agricultural sector into several areas, this division will be further explained. On the bottom of the energy sector stands the category 'Other', in which emissions from fuel (both – for heating and transport purposes) combustion are located. These emissions are produced in all sectors – agriculture, forestry, and fishery. Unfortunately, there were no data available regarding fuel consumption in the agricultural sector, and because of that, the total amount was used and analyzed. In agriculture, forestry and fishery usually utilize:

- stationary combustion appliances – liquid, solid-type fuel, gaseous fuel and biomass;
- district transport and other mechanic systems – gasoline and mainly diesel fuel;

The agricultural sector emissions are calculated in the following categories:

- agricultural lands;
- intestinal fermentation;
- manure;
- land liming;
- urea utilization [265].

In Figure 2.5, the division of emissions in the agricultural sector, the type of produced emissions and in what area of the sector is explicitly shown.

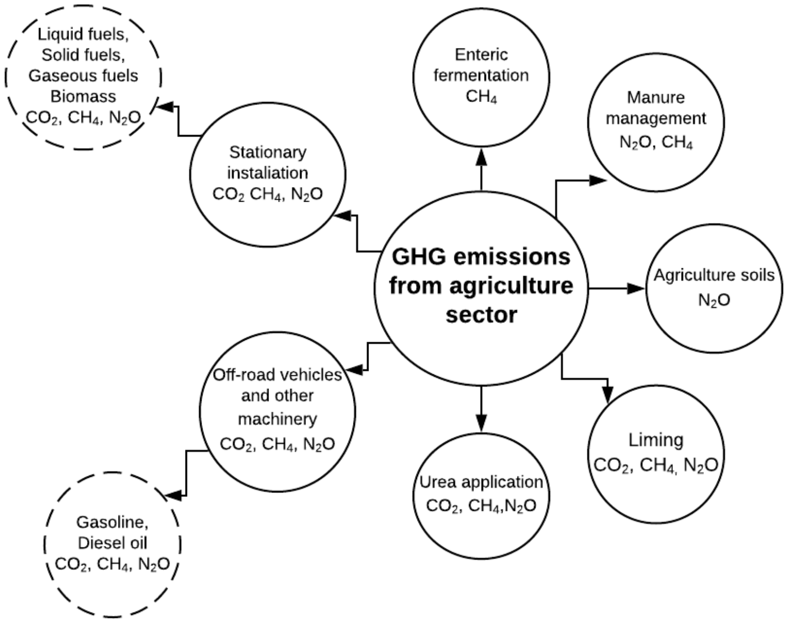


Fig. 2.5. Breakdown of emissions from the agricultural sector.

This research aimed to see if there would be a potential energy and emission savings from implementing energy management actions and propose a framework for the energy management system in the agricultural sector on a company level.

2.5. TIMES model

2.5.1. Modeling Approach

The selected modeling approach through TIMES allows for linking energy sector consumption and conversion technologies with other sectors [31]. The TIMES model parameters consider resource limits and costs, operating and maintenance costs of product production technologies, and the demand for specific products and allow the definition of new parameters in the model, such as the added value of the product. Simulations of the model allow us to capture both mid- and long-term results. Besides biomass flows, the model allows us to include by-product and waste flow definitions for processes in biorefineries, and, finally, the model is an optimization model that helps to find and select the best scenario for bioeconomy development considering the least expensive solutions for various technologies. The chosen modeling approach applies optimization to discover the most economically feasible solution to reach the determined goal—to achieve a 30 % added value in 2030 with the production of new products with a higher added value by introducing new technologies and using residual products as raw materials. For scenario investigation in this research, back casting is used - it starts with the definition of the preferable future and further works backward to spot the necessary measures to reach the targets.

The TIMES bioeconomy value model (TIMES-BVM) is designed to model bioresource flows and technologies for the development of the animal husbandry sector; however, it can be modeled to research other sub-sectors in agriculture, such as cereal farming, field plant production, greenhouse horticulture, and others. The aim of the model is to help understand how the agricultural sub-sector can contribute to meeting the higher value-added goal for bioresource growth for 2030. The model addresses the development of biorefineries from the perspective of natural limits (the capacity of resource application), economic viability (technology, maintenance, and operation), and socio-economic aspects (increased salaries, etc.).

The model created in the research is used to find the most economically viable scenario for increasing the value of bioresources. It is achieved through an optimization-type simulation, which uses historical data from 2015 to 2019 and a forecast of future industry development trends as well as opportunities to use new bioresource technologies to produce higher-added-value products starting in 2023.

2.5.2. Data Analysis and Inventory

The model structure is created based on the general TIMES-BVM structure, including resources (in this case, primary livestock resources such as eggs, meat, milk, wool, and honey), technologies (pre-processing and preparation of raw products; production of food, feed, and other products; and processing of by-products), product flow (import, export, and domestic production) and demand. Processes used in the structure are divided into primary production, import and export processes, transformation activities like those in biorefineries, and product demand (see Figure 7). These elements are defined based on data from statistical databases, such as the Central Statistics Bureau (CSB) of Latvia, Eurostat and Faostat databases, those from the literature, interviews of companies, and approximations.

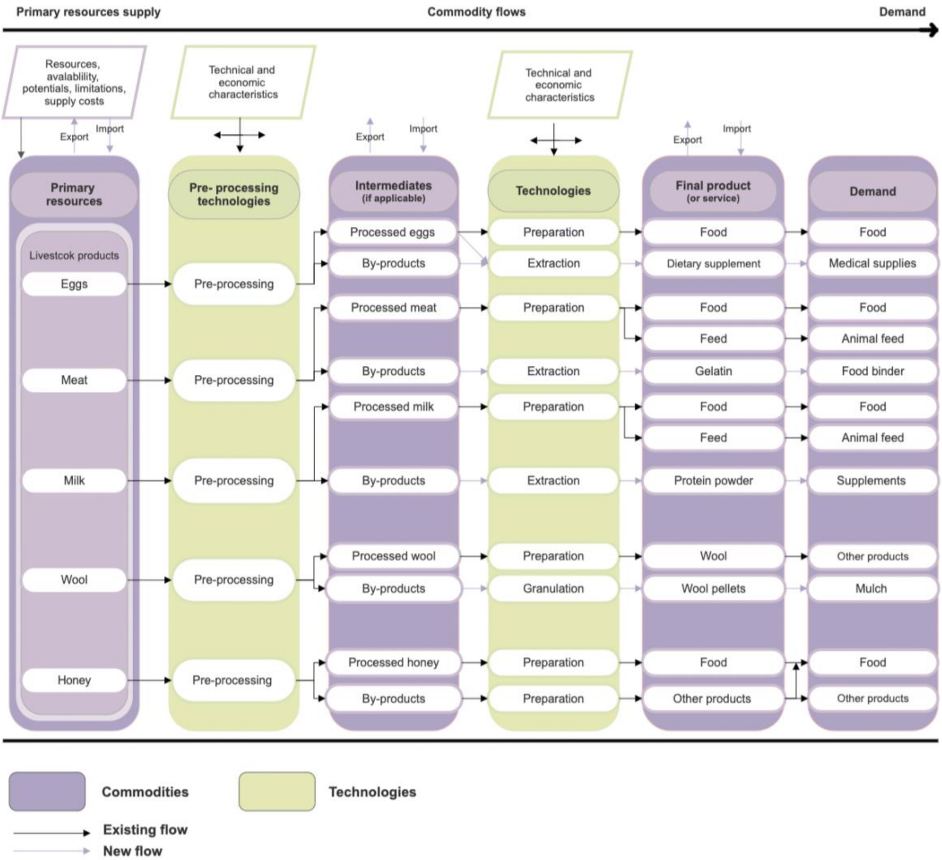


Fig. 2.6. BVM TIMES Livestock model structure.

The model includes four bioresource stages: primary and processed resources, final product, and demand. Various technological processes are integrated for primary resource supply in terms of local and imported resources, costs, efficiency, capacity, availability, and limitations of processing technologies for primary and secondary resources. Each conversion path in the simulation of the model is calculated through an optimization approach, and the results show the best solution to satisfy the demand at the lowest cost. The results include the technical and economic characteristics of the pathways based on the model inventory. The model output is produced as a quantitative result for biomass flows and new capacity additions for technologies used in the production of products to meet the demand, the overall costs, and the overall added value of the products supplied, shown in Table 1.

Table 2.10.

TIMES-BVM model input data

Constituent	Variable	Measure of Unit
	Type	Domestic harvest/import
	Stock Cumulative Value	Thousand tons, kt

Primary resource supply	Cost	EUR/kt
	Yearly production	Thousand tons, kTt
	Limitations	Upper/lower
	Flow	Input/output items
Conversion (existing and new technologies)	Flow	Input/output items
	Efficiency	%
	Existing Installed Capacity	Thousand tons yearly, kta
	Utilization	%
	Investments	EUR/kta
	Lifespan	Years
	Fixed costs (maintenance and operating)	EUR/kt
	Added value	EUR/kt
	Limitations	Upper/lower
Demand	Demand value	Tkt

The structure of TIMES-BVM requires the definition of product demand for the selected target year of simulation, and it is carried out by applying a forecast based on regression analysis according to methods introduced in the literature [267]. Input data for the request of finished products are fixed on prediction based on regression analysis for the years up to 2030. Regression analysis is performed prior to running the model. The demand for the finished product is a dependent variable in regression analysis.

The data input for resource import, export, and domestic production values is based on the extrapolation of statistical trends from 2015 to 2019 with the help of regression analysis. These values have upper and lower boundaries entered the model in the range of ±10 %, except for meat, which has a range of ±25 %. These ranges allow tradeoffs among other processes to fulfill the demand within the given set of limited capacities of technologies and resources. The selected boundaries allow production to match the demand and the avoidance of model instabilities due to poor statistical data availability and quality. This assumption allows the avoidance of shortages or surpluses that are neither consumed nor exported.

2.5.3. Honey

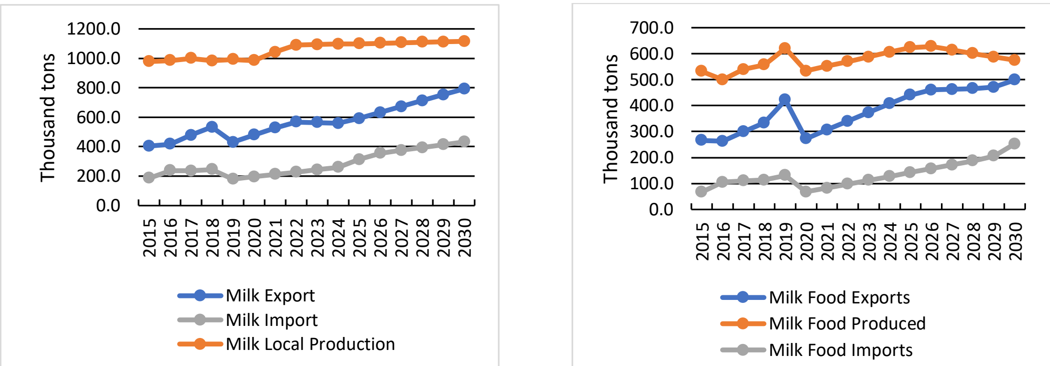
In the case of honey production in Latvia, the statistics of the honey industry are wildly inaccurate because some honey is legally sold without official accounting and without paying taxes. The approximate amount of honey produced in a certain year is determined by multiplying the average amount of honey produced in one farm by the total number of farms in operation in the given year.

According to CSB statistical data, the amount of honey produced in 2018 was 2000 t, while according to calculations made in accordance with the method described above, it was 3809 t, which is almost 2 times higher. For the purposes of the study, the latter amount of 3809 tons was used in the model. Since there is no record of honey consumption in Latvia's statistical database, it was assumed to be 100 % - everything produced is also consumed. It should be considered that honey is not just one final product, and it differs depending on the flower nectar from which it is obtained. Thus, there are differences in both price and demand depending on the type of honey. Regardless of this factor, the price of honey is very stable, and there are no fluctuations in price observed. To increase the value added in the honey production industry, products such as honey, beeswax gums, face creams and soaps, royal jelly (nutritional supplement), propolis, and pollen (natural antibiotics) can be produced but have not been studied in this research further because of insufficient data.

2.5.4. Milk

Dairy farming in Latvia is a traditional and highly developed industry. It is one of the most important sub-sectors of the agricultural sector in Latvia. According to the CS data, the number of dairy cow herds is decreasing annually. In contrast, the milk yield from one cow shows a positive trend. In 2002, the average milk yield from one cow in Latvia was 3.96 t [33], but now, it is already remarkably close to the average European cow productivity, which was 7.5 tons in 2020 [34]. Despite considerable progress, the Central Union of Dairy Farmers of Latvia (LPCS) claims that it is no longer profitable to produce dairy products in Latvia [270].

According to the survey of local dairy farmers, it can be concluded that for several years in Latvia, there has been a tendency to import the milk needed for dairy processing at lower prices instead of using local milk. The analyzed statistical data and forecasts based on extrapolations used as the data inputs for the model (see Figure 8) show a steady trend in domestic milk production. At the same time, an upward trend in import and export, while a downward trend is visible in domestic milk food (processed dairy products) production, which provides products with higher added value, and an upward trend is observed in exported and imported milk food products.



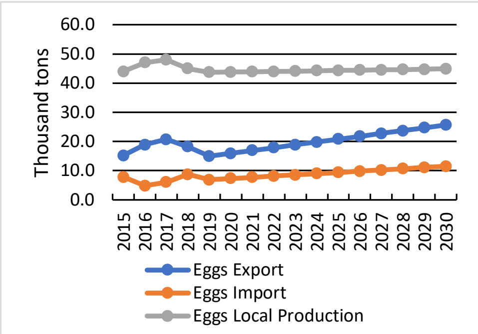
(a) (b)

Fig. 2.7. (a) Milk import, export, and local production; (b) Milk food import, export, and local production.

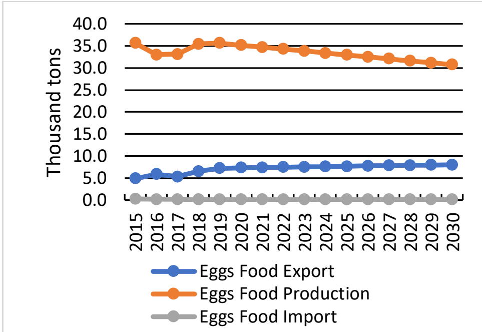
Potential products could be protein powder, agricultural fertilizer, polymers, alcohol, lactic acid concentrate, animal feed, etc. [271][271][271][271]For each farm to find the most efficient and best solution, it is necessary to understand not only the seriousness of the situation in the development of future scenarios but also clarify the expertise required, how to assess it, and information on available public support.

2.5.5. Eggs

In the egg market in Latvia, the number of eggs laid is constantly increasing, and more is produced than is needed for the local market, so a large part is exported. The extrapolated statistical data presented in Figure 9 are used as input for the model. In Figure 9b, the forecast shows that a significant drop in domestically produced egg produce (processed products) can be expected, while the import of egg products remains constant.



(a)



(b)

Fig. 2.8. (a) Egg import, export, and local production; (b) Egg Food import, export, and local production.

As egg whites, yolks, and eggshells contain many valuable substances, these could be used to produce health-promoting products. Chicken eggshells consist of 95 % calcium carbonate, an excellent filler in composites, which is easy to use in production due to its low specific density [35]. Since calcium builds and ensures healthy bones, egg powder, which contains substances such as magnesium, fluoride, and other minerals, can also serve as an effective calcium supplement [36]. Therefore, it is essential to explore the possibilities of producing eggs for primary consumption, export, and products with higher added value, which could benefit the development of local egg production.

2.5.6. Meat

Poultry plays an important role in the meat industry, with chicken meat accounting for the largest share. The extrapolated statistical data shown in Figure 10 are used as input for the meat section in the model. The statistical data and forecasts made show that the total demand for meat food (processed meat) in Latvia will decrease in the future (see Figure 10b). There is a significant decline in local meat (raw) production from 2019 to 2023. Although the upward trend in meat production resumes in 2024, it is slow and stagnant compared to the huge jump in imported meat volumes that can be observed already from 2020. The production of meat products (see Figure 10b) for the local market will remain almost unchanged in 2030, while the export, import, and production of meat products for processing into products with a higher added value will consequently decrease.

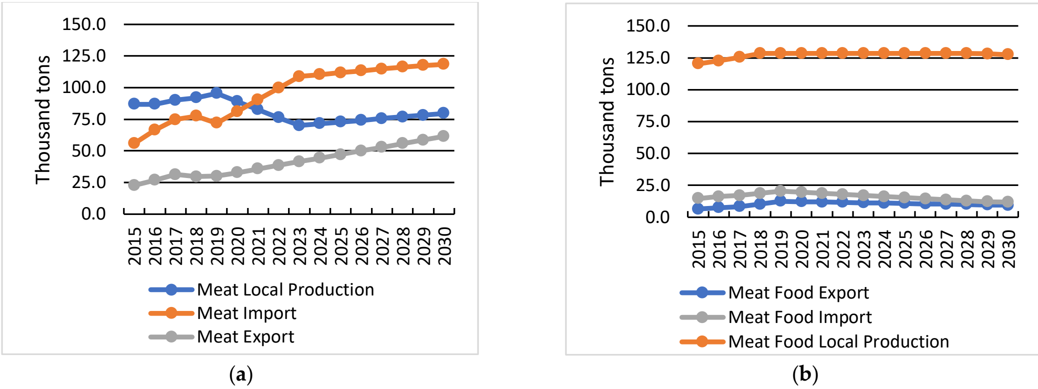


Fig. 2.9. (a) Meat Import, Export, and Local Production; (b) Meat Food import, export, and local production.

Potential products with higher added value considered in the model are biogas (for example, turkey tails, etc., where the fat content is particularly high), animal feed (bones, dog treats, etc.), gelatin, lime, broth, bone paste and powder, various extracts, protein of animal origin, and collagen.[274][274][274][274]

2.5.7. Wool

The input data for wool (raw) used for the model are shown in Figure 11. According to the statistical data analysis and trend extrapolation, exported wool is rising rapidly, while the amount of exported wool products with higher added value is falling rapidly. Although wool imports are growing rapidly, the demand for wool product imports is forecasted to decline. Domestic wool production, on the other hand, is slowly growing, while production volumes of domestic wool products remain constant.

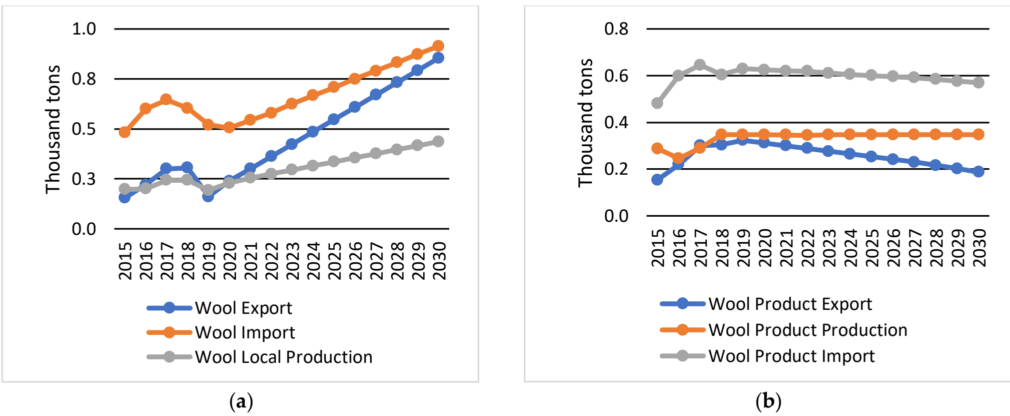


Fig. 2.10. (a) Wool import, export, and local production; (b) Wool Product import, export, and local production.

According to the current situation, wool export will continue to decrease, and even in local wool processing, no improvements are expected. Wool production is related to the production of sheep meat and the number of sheep. According to the statistics, there is a decreasing trend in the number of sheep in Latvia since 2017. The trend of local wool production is directly dependent on other influencing factors, such as the development of the meat market.

2.5.8. New Technologies for Higher-Added-Value Products

The new technologies to produce higher-added-value products included in the model structure are:

- dietary supplement production from processed eggshells;
- gelatin production from meat-processing by-products;
- protein powder production from milk-processing by-products;
- production of wool pellets from wool-processing by-products;
- production of honey-derived products from honey by-products.

The limit for the availability of new technologies in the model is set to 2023, signifying the current possible implementation of these technologies. The production amounts are limited by the available by-products and waste products from existing processes. Therefore, the production of new products with higher added value depends on the demand and thus also the local production of the conventional products. The demand was defined based on the historical average market data for these segments [275]:

- calcium carbonate;
- gelatin and its derivatives (excluding casein glues, bone glues, and isinglass);
- protein concentrates and flavored or colored sugar syrups;
- pellets and briquettes of pressed and agglomerated wood and of vegetable waste and scraps.

The added value of the item is recognized as factor costs and is established as the gross earnings of biorefineries (salaries included) for operating activities. It is estimated based on the official CSB available data on the market-added value and produced volume of goods.

2.5.9. Other Assumptions and Limitations

Other factors limiting the use of by-products within the model were assumptions about technologies—process efficiencies; resource and product prices and costs; and upper and lower limits on the import, export, and local production of raw resources and final products—as they influence the commodity balance and thus indirectly influence the need for resource processing, resulting in different amounts of by-products and, consequently, different amounts of new products.

While the energy efficiency of the European Union’s agriculture has remained relatively constant over the years, the energy efficiency indicators of Latvia’s agricultural sector show a downward trend from 2010 to 2017. The total consumption of energy resources of the agricultural sector has increased year by year since 2010, while the turnover of manufactured products has not been able to generate a sufficiently competitive economic contribution to compensate for the increase in energy consumption. To increase energy efficiency, it is necessary to implement energy management, which is the intelligent and efficient use of energy to maximize profits while reducing costs [39]. Moreover, energy management is related to the economic and environmental aspects to eliminate the inefficient and reckless use of resources, which in turn causes global warming [40]. The data used in the model and the model itself do not consider any potential benefits that could result from the application of energy efficiency measures in the agricultural sector and that could derive from the implementation of energy policy goals. Also, the impact of breeding and genetics, as well as welfare and feeding, on the productivity of production is not considered in this study.

2.5.10. Validation of the Results

Mass balance validation is used as a crucial element in the TIMES model to guarantee the robustness of the findings. Potential discrepancies in the representation of commodity and resource flows can be found and corrected using mass balancing. Mass balance calculation for the obtained results ensures uniformity and precision of the results obtained. The mass balance calculation is adopted from the EN 16785-2 standard "*Bio-based products—Bio-based content—Part 2: Determination of the biobased content using the material balance method*" [273] as shown in Equation (1):

$$\sum M_{in,i} = \sum M_{lo,j} + M_{t,out}, \quad (2.15.)$$

where:

$M_{in,i}$ is the mass, expressed in kilograms of the input commodity i entering the production process under consideration;

$M_{lo,j}$ is the mass, expressed in kilograms of the loss i in the production process under consideration;

$M_{t,out}$ is the total mass of the product, expressed in kilograms, leaving the production process under consideration.

When discrepancies in mass balance are found, additional research is conducted to determine the precise causes and probable sources of errors in the model assumptions. These could be typographical errors in data entry, insufficiency of data sources, or unrealistic modeling assumptions. Once the differences are identified, the necessary corrections can be made to guarantee a more accurate depiction of the model simulation outputs.

2.6. System dynamics

This research aims to create a system dynamics model using Latvian dairy farming as a case study. It would not only provide an insight into the system's structure but also identify the system's weak links and allow for the development of recommendations.

The system dynamics model was created based on the operating principles and data of one of the largest and most modern agricultural enterprises. Its main product is milk. There are about 470 dairy cows, and the average milk yield is 10 184 kg per cow per year, while the total milk production is 4736 t per year. In total, there are three barns in the dairy complex where all the necessary animal welfare regulations and environmental requirements are observed. To execute the construction of cowsheds, the owner has implemented several projects of the European Agricultural Fund for Rural Development, which has enabled the introduction of innovations in the farm. This therefore increases the efficiency of farming, as well as provides the most suitable conditions for all ages of the livestock. Several projects were implemented, but the most important of them were:

- construction of the new barn, in 2012, which cost 2 641 915 € with a payback time of 10 years,
- construction of liquid manure storage in 2015, which cost 135 435 € with a payback time of 8 years,
- construction of a new livestock shed in 2020, which cost 1 864 564 € with a payback time of 9 years,
- purchase of a Siloking feed mixer/distributor in 2020, which cost 190 000 € with a payback time of 5 years.

Based on the operating principles of the farm, it can be safely stated that this company can serve as a positive benchmark for the Green Deal goals of the future.

To obtain all the necessary information, a literature analysis was carried out, in which scientific articles mainly from SCOPUS, ScienceDirect databases, Google, Google Scholar, and statistics and policy documents like European Commission reports and Latvia's national plans, reports and strategies were analyzed. A combination of the following search requirements were used in the process of finding relevant information and articles: "Agriculture", "Latvia", "Europe", "Climate neutral", "Sustainable", "Carbon farming", "Green Deal", "Greenhouse gas", "Renewable", "Strategy", "Energy", "Production", "Efficiency", "National Energy and Climate plan", "Guidelines", "Economic", "Technical", "Technology", "Livestock", "Dairy farming", "Manure", "Production", "Policy", "Innovation", "Feed", "Quality", "Investment", "Thermoregulation", "Feed", "Yield", "Improvement", "Management", etc. Priority was given to the most recent articles and papers of relevance, scientific articles published in peer-reviewed journals in English. Then, one of the biggest and most modern dairy farms in Latvia was surveyed, which has already implemented several innovations for precise management, livestock welfare, modern technologies, and energy efficiency measures, while achieving a yield that significantly exceeds the average annual milking yield of a cow in Latvia and Europe. The farm owner was asked questions such as: Opinion on the Common Agricultural Policy, Carbon Farming and Support Mechanisms; Information about the company's specifics, boundaries, affiliated companies, their cooperation, the importance of cooperatives, the impact of innovations on the company's energy consumption, and the effectiveness of welfare implementation in relation to milking yield; the point of view of industry professionals on the biggest obstacles, as well as the experience of overcoming them; History of the company, its development, etc. These questions were mainly used to expand the research not only with the theoretical knowledge, but also with field professional knowledge who practically work in this field daily, while later connecting practical and theoretical knowledge by making calculations with data obtained from a real company to be able to draw the most objective conclusions and avoid any blind spots. Data were obtained from this farm and processed, such as data on energy consumption and milk yields by years, the introduced innovations and their specifics, the amount of manure produced and its processing, the amount of feed consumed, changes in number of cows and other related data; then, calculations were made. Subsequently, a system dynamics model using Latvia as a case study was made, which would not only provide an insight into the system's structure, but also identify the system's weak links and allow for the development of recommendations. The flow chart of the research development is show in Figure 2.11.

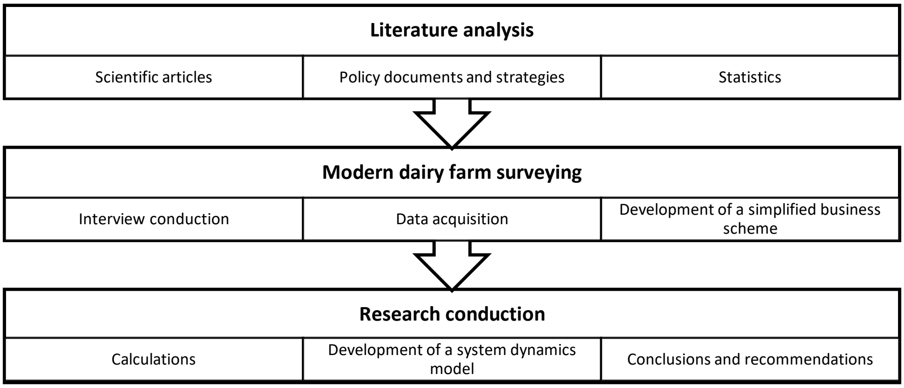


Fig. 2.11. Flow chart of the research development.

The Stella Architect modeling tool was used to create a simulation model to present in a simplified mathematical way an agricultural sub sector—dairy farming. It was chosen because it not only shows the structure visually, but also includes numbers, equations, and mutual interactions of various influences. It includes economic, environmental, and technological aspects. To create a transparent insight into the structure of the dairy farm linked to the research objectives and focus, a simplified scheme was created (Fig. 2.12).

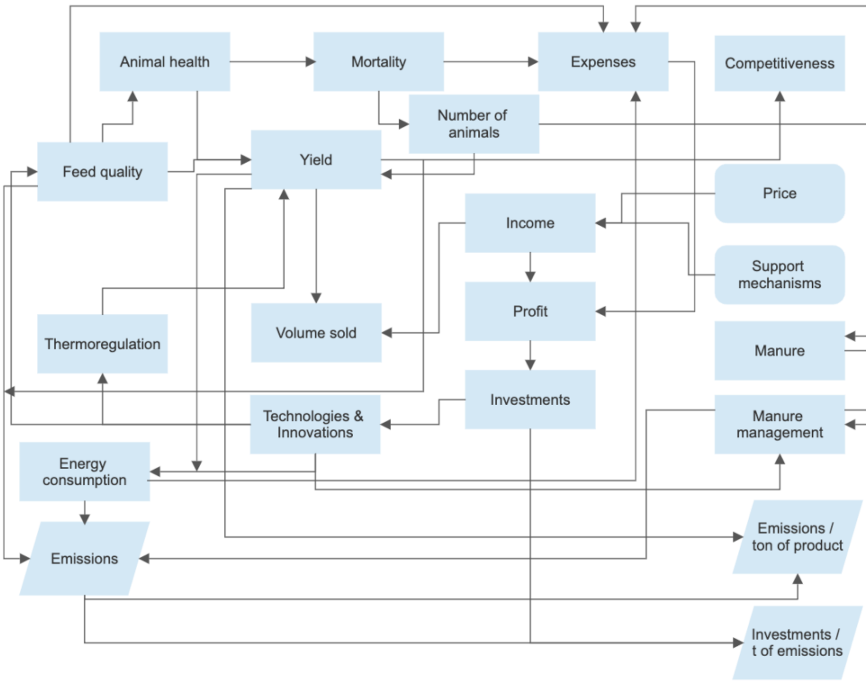


Fig. 2.12. Simplified operation scheme of the dairy farm.

The main schemes were shown in a simplified way and included both thermoregulation and the impact of feed quality not only on yield, but also on animal health, which in turn affects mortality, expenses, product price, and thus competitiveness. The impact of support mechanisms and the amount of sold volume were also considered, which affects savings, and in turn later allows or prevents investments in new, modern technologies that would reduce expenses and increase energy efficiency, yield, and total income. Manure processing is also included as an integral part of animal husbandry. The impact of these processes on the generated emissions is also indicated, and the investments required to reduce them are included.

Model data input comes from two sources—literature analysis and data obtained from the specific company's survey. Data such as the number of cows, electricity and heat consumption, investments in various technologies and modernization, and milk yield were used for the case study.

The purpose of the model is to create the operation model of the dairy farm, which reflects the importance of investment implementation both in an economic and environmental context, where it is possible to observe the amount of emission reduction. It is possible to predict the importance of the implementation of investments and changes in emissions considering several interrelated influencing factors in the dairy farm model. To identify the main drivers and weak links, it was necessary to model the importance of investment implementation and the change in emissions. In general, the model was divided into four sectors:

- dairy cows;
- investment in dairy farming;
- economic factors;
- emissions.

For the construction of the base model to be as close as possible to the real-life situation, it was necessary to look at several sectors in more detail, so that the model is not based on assumptions, but on real data. One of the sectors that needs to be further divided into sub-sectors is investments in the improvements of dairy farming, where it is also necessary to consider separately the investments in the improvements of feed quality, thermoregulation, and manure management. Another sector is the economic factors, where it is necessary to study in more detail both how the savings are generated, which is a key factor needed to make the investment, and the cost of capital, which determines the total one-time costs needed to cover, e.g., construction of a new barn.

Each sector was modelled so it could be used for each emission scenario. Once the boundaries of the model study were defined, it was determined that the emissions generated would be viewed in two ways:

- generated emissions, which will be measured in ktCO_2eq year,
- generated emissions per product, which will be measured in ktCO_2eq to the annual production volume.

It was further determined that the change in emissions in the model would be determined in 3 scenarios:

1. The dairy farmer does not invest in any of the dairy farm performance improvement measures;
2. The dairy farmer invests only in improving manure management;
3. The dairy farmer invests in all farm improvement measures.

The scenarios were created since dairy farmers have more pressure from the state to invest in manure management than in feed quality and thermoregulation. From the first two scenarios, changes in emissions were observed, while in the third one, changes in emissions to produced production will be observed. It should be mentioned that although the model structure is created for the third scenario, it has the possibility to disable some parameter behaviour, thus creating some other scenario.

So that the data obtained by the model could be compared with the real-life situation and conclusions could be drawn, it was chosen to simulate the model in the period from 2012 to 2022. All data used in the model are obtained from dairy data, adopted considering the opinion of sector experts and literature analysis.

2.6.1. Dairy cows

Dairy cows are the most important element in a dairy farm, as the obtained raw milk is the main product that brings profit to the company. Dairy cows are mostly at least two years old and have reached their first lactation. The cow sector in the model consists of two main stocks: dairy cows and sick cows (Figure 2.13).

Dairy cow stock has both outgoing and incoming flow. To increase the number of cows, the owner buys new dairy cows or grows heifers. If a cow's milk production drops, it is sold. Sick cows are treated, but when the treatment is unsuccessful and requires a lot of resources that would affect not only the costs, but also the yield, they are usually sent to the slaughterhouse or die naturally. Livestock health is particularly affected by the availability of high-quality feed, living conditions, and thermoregulation.

The incoming flow of the stock of dairy cows was determined considering the maximum number of beds for cows in the barn. But the outflow of the stock "sales" is determined by multiplying the sales ratio by the number of milking cows.

A similar principle applies to the cure and mortality flows of the sick cow stock, but the inflow of sick cows is affected by the level of feed quality. The effect of feed quality on morbidity is derived from a non-linear relationship in which the feed quality rating is used as an argument. The effect on morbidity ranges from 0 to 1.

Cows also produce manure from their digestive system. Manure can be divided into liquid and litter (solid). Litter manure is cow excrement with/without litter and fodder remains, and liquid manure—with urine and/or water admixture. The total amount of manure produced was calculated as tons/year.

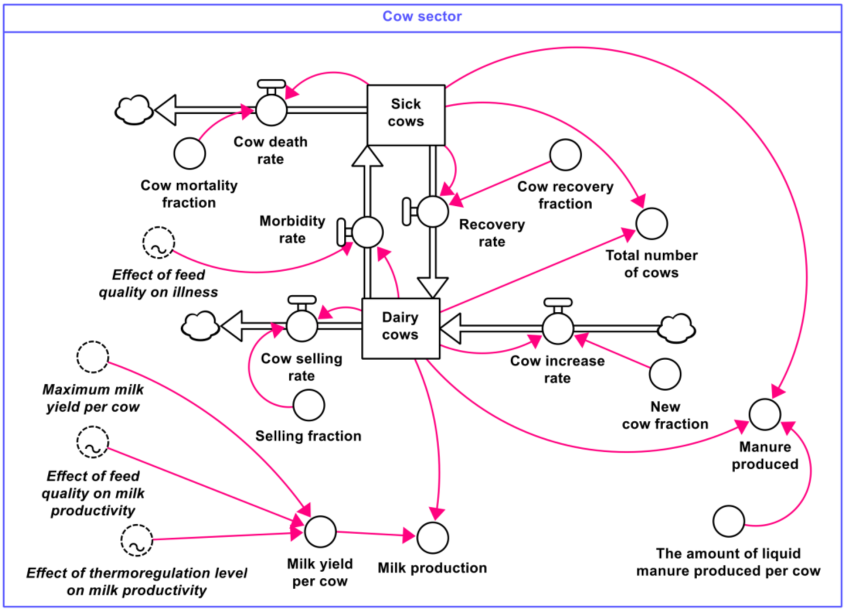


Fig. 2.13. Structure of the cow model.

The quantity of milk produced and sold [t] depends on the number of cows and the average yield of one cow. In general, milk yield per cow is influenced by several parameters, including the effect of thermoregulation level and feed quality on milk yield. Both the effect of feed quality and the effect of thermoregulation on hunger are characterized by a non-linear relationship that varies in the range from approximately 0 to 1, in which the rating of feed quality or thermoregulation level is used as an argument. In the model, the average milk yield at the beginning of 2012 is taken from the data of the reviewed dairy farm, to then be able to compare how investing in thermoregulation and feed quality improvement technologies increases milk yield.

The necessary data were obtained from the dairy farm, available statistical data, and scientific literature analysis. System dynamics model parameters for the cow sector can be seen in Table 2.11.

Table 2.11.

System dynamics model parameters for the cow sector

Parameter	**Unit of Measure**
Mortality rate	Dimensionless
Increase in the number of cows ratio	Dimensionless
Cow sales ratio	Dimensionless
Cow cure ratio	Dimensionless
The amount of liquid manure produced per cow	tons/year
The amount of litter manure produced per cow	tons/year
Number of milking cows	Number of cows
Maximum number of cow places in the barn	Number of cows
Maximum milk yield per cow	tons/cow/year

2.6.2. Emissions

The emission sector in the model represents emissions from the company, as well as emissions per unit of production. It is necessary to calculate the emissions to be able to evaluate the progress towards climate neutrality. In dairy farming, the main GHG emissions come from intestinal fermentation and manure management. Although in the documentation, the calculation of emissions from fuel consumption, electricity, and heat production is below the energy and transport sector, it is important to include it. In the model, the emission sector has two main stocks and two main flows (Figure 2.14).

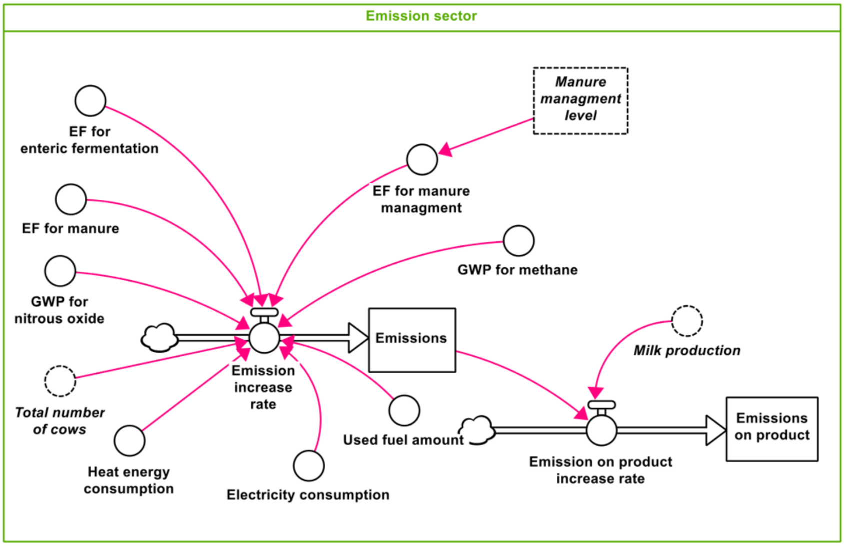


Fig. 2.14. Structure of the emission model.

Methane emissions from intestinal fermentation processes, GHG emissions generated to produce the consumed electricity and heat energy, as well as GHG emissions generated due to fuel consumption were calculated. Manure emissions were also calculated; however, several parameters must be considered when calculating manure. Organic matter and water make up most of the composition of manure. Manure emits both methane and nitrogen oxide emissions. How much methane is released from manure depends on its oxygenation, water content, pH level, and feed digestibility [273]. How much nitrous oxide is produced depends on climate, pH, and manure management. To be able to perform a unified accounting of emissions, it is necessary to switch to CO_2eq. In general, both dairy farm data and predetermined constants were taken for the calculation (Table 2.12).

Table 2.12.

Input data for the emission sector in the model

Parameter	Unit of Measure
Heat energy consumption	MWh/year
Fuel consumption	litre/year
Diesel fuel combustion	MWh/ton
Electricity consumption	kWh/year
Global warming potential of CH_4	Dimensionless
Global warming potential of CO_2	Dimensionless

Electricity and heat consumption are currently represented as constant values in the model. It is also necessary to calculate the emitted emissions per production quantity, which can be calculated by dividing the generated emissions by the produced production quantity.

2.6.3. Economic factors

It is important to investigate the economic sector as it is one of the determinants of investment and savings, providing a safety net and a sense of security for a farmer that the company will have a better chance of getting out of financial difficulties after taking risks on new investments [273]. In dairy farming, the biggest expenses come from electricity consumption charges, dairy cow treatment costs, and capital costs, while income comes from milk production and sales, where they are affected by the amount of milk sold, which depends on the yield obtained from the cow. Cow and milk prices determined by the cooperative, additional income also comes from the sale of culled cows, where the price per cow depends on the market. Income is exactly the factor that contributes to the accumulation of profit, because even if the expenses are very high, if there is a large income, the accumulated profit will also be within the norm. A feedback loop is also created from the amount of accumulated profit because investment decisions are made from the amount of accumulated profit and own available financing. If a decision is made to make investments, then the reduction in retained earnings is determined by the channeling of funding to investments and the self-financed part (Figure 2.15).

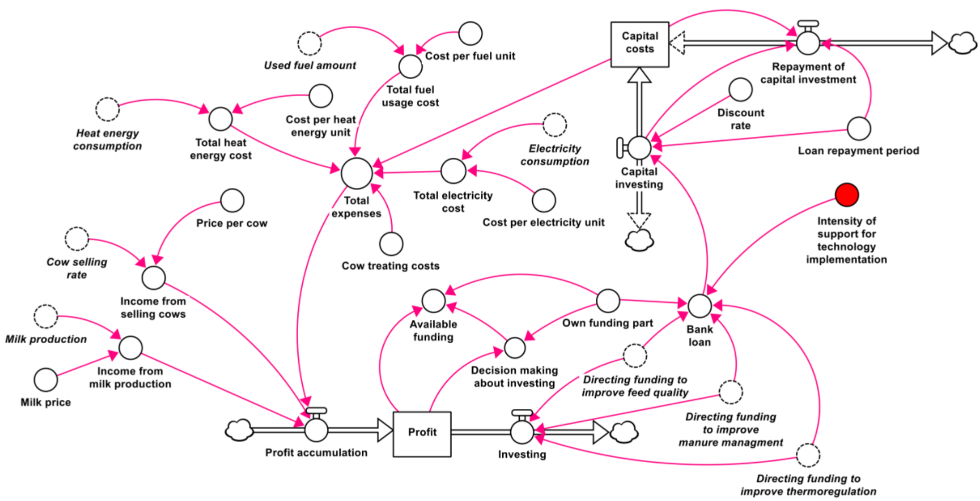


Fig. 2.15. Structure of the economic model.

The capital cost sector consists of one main stock - capital cost, the increase of which is determined by making capital investments, which is affected by the discount rate, bank loan, and the loan repayment period, while the reduction of the stock is affected by the repayment period, the capital investor, and the capital costs themselves. A dairy company needs to take a loan from a bank to cover the costs needed to make improvements to the farm which are not compensated for by the support offered by the state.

For the sector to work in the model, it is necessary to enter data; therefore, the input data used in the savings and capital expenditure sector are summarized in Table 2.13.

Table 2.13.

The input data in the savings and capital expenditure sector

Parameter	**Unit of Measure**
Heat energy costs	€/MWh
Fuel costs	€/liter
Cow cure costs	€/year
Cow costs	€/cow
Voluntary related support for milking cows	€/cow
Share of own financing	Dimensionless
Intensity of support measures	Dimensionless

2.6.2. Investments in dairy farming

To manage dairy cow manure, it is possible to use different management methods. Each type of manure management in the model is evaluated in points, where they determine the level of management on the farm. Each type of management has its own determined emission factor (Table 2.14).

Table 2.14.

Manure management method, level and factor

Management Method	**Management Level, Points**	**Emission Factor** [42]
Deep bedding + mixing	1	0.07
Solid storage	2	0.02
Liquid systems	3	0.0005
Anaerobic lagoon	4	0.001
Biogas production	5	0.0006
Biomethane production	6	0

The model considers the time required to implement improvements at the management level (Figure 2.16). The improvement of the level is also influenced by the ratio between the funding diverted for improvement and the investment required to improve manure management by one point. The necessary investment for improvement per cow is determined by the necessary investment for raising the quality indicator by one point, the difference between the maximum and management level in the farm, as well as the available support measures. To determine whether it is worth investing in the improvement of manure management, the time implementation of improvement measures is determined by whether the improvement of manure management contributes to an increase in income. If the manure is used to produce biogas, it is possible for the dairy farmer to receive payment for the manure sold to the biogas plant, unless the farmer himself has invested in the biogas plant.

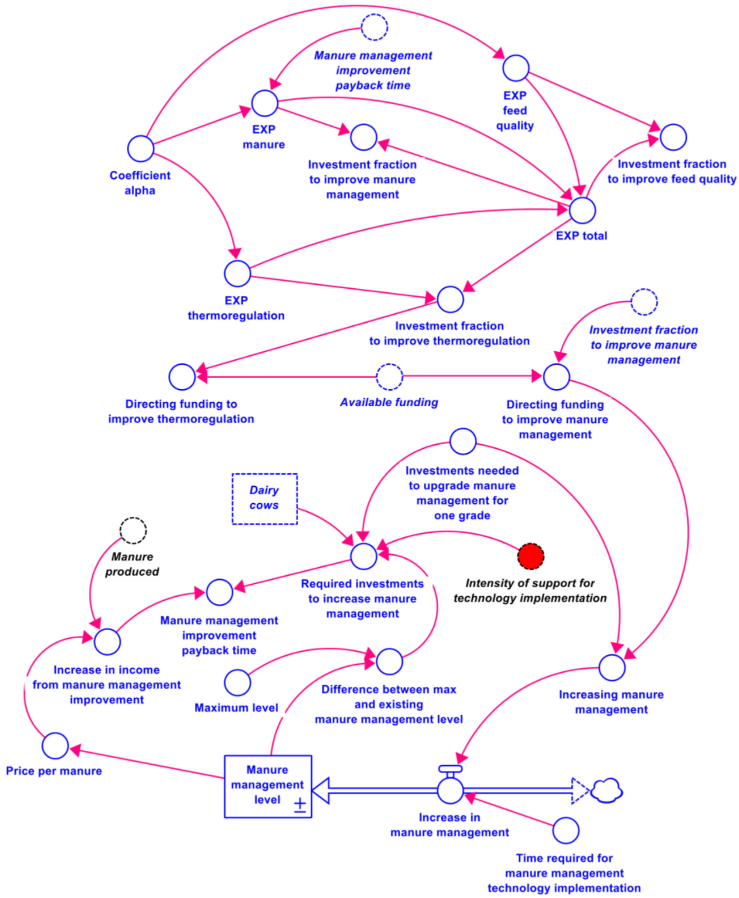


Fig. 2.16. Structure of the investment in manure management model.

Feed quality is included because it affects milk yield, the health of cows, generated emissions, and the farm's profit (Figure 2.17). The most important indicator by which feed quality is determined is feed digestibility (%). In the model, feed quality is measured on a scale of 1 to 10, where 1 is the worst feed quality indicator and 10 is the best. However, to achieve high feed quality, it is necessary to invest in technologies to achieve the set goal. The effect of feed quality on milk yield varies between approximately 0.1 and 1 and is derived from a non-linear relationship using the feed quality score as the argument. The model also examines how income could increase as feed quality increases to determine the payback period. The increase in feed quality is affected by the time it takes to introduce a new technology, as well as the ratio between the funding diverted to improve quality and the investment needed to improve quality by one point. The necessary investment for improvement per cow is determined by the necessary investment for raising the quality indicator by one point, the difference between the maximum and the existing level of feed quality on the farm, as well as the available support measures.

It is crucial to make improvements in thermoregulation to improve the well-being of livestock, which would also affect the milk yield significantly and reduce diseases. In the model, the level of thermoregulation is evaluated on a scale from 1 to 10, where 1 is the worst thermoregulation, and 10 is the best. The effect of thermoregulatory level on yield varies between 0.1 and 1, and is derived from a non-linear relationship using the thermoregulatory level score as an argument. The model also explores how earnings could increase if the level of thermoregulation is increased to determine the payback period (Figure 2.17).

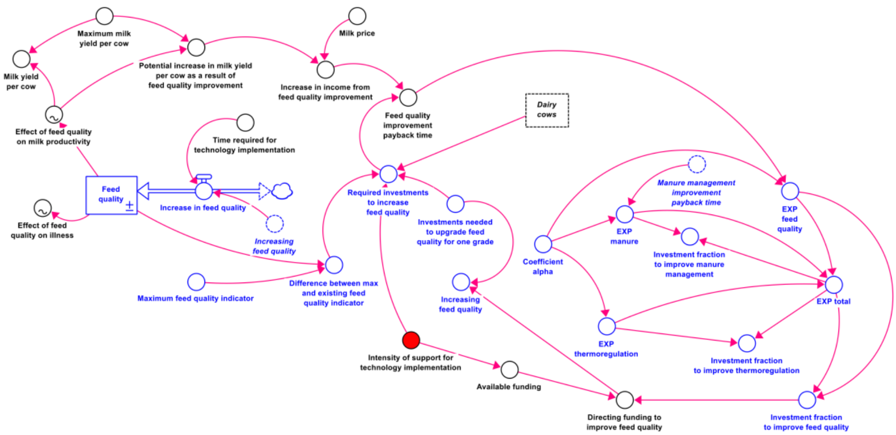


Fig. 2.17. Structure of the investment in feeding quality model.

The increase in the quality of thermoregulation is also affected by the time it takes to implement a new technology, as well as the ratio between the funding diverted to improve thermoregulation and the investment to improve by one point. The necessary investment for improvement per cow is determined by the necessary investment for improving thermoregulation by one point, the difference between the maximum and existing levels in the farm, as well as the available support measures. For the model to function, the data reflected in Table 2.15 were entered.

Table 2.15.

Input data for the technology development

Parameter	Unit of Measure
Time to implement	Years
Manure price	€/ton
Max level	Points
Initial level	Points
Investments for technology improvement for one point	Points

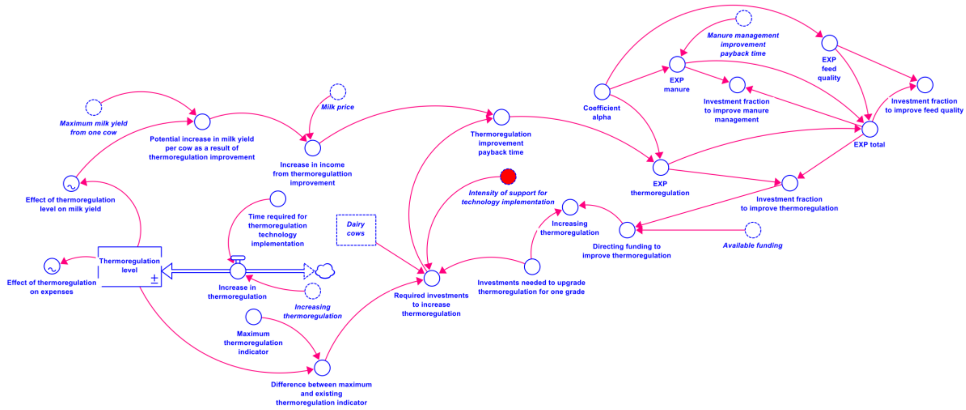


Fig. 2.18. Structure of the investment in the thermoregulation model.

3. RESULTS

3.1. Carbon balance results to evaluate a sustainable production of biogas

To objectively determine the total greenhouse gas emissions from fuel use (fuel emission indicators per 1 ha of cultivated maize area for each process are collected and shown in Table 3.1), it is necessary to convert them into a single unit of measurement – CO_2 equivalents (see Table 3.2). As the global warming potential (GWP) of 1 t of CH_4 equals 25 t of CO_2 and 1 t to N_2O equals 298 t of CO_2, these values are used to produce total greenhouse gas emissions [133].

Table 3.1.

Fuel emission indicators per 1 ha of cultivated maize area

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

After summarizing the results, in 2017, GHG emissions are generated for the cultivation of maize, which was used as a substrate for biogas production, in total 3.53 ktCO_2eq/year to treat it with heavy agricultural machinery, which uses diesel fuel. Knowing that 5382 ha of biogas maize were managed in 2017, a result is obtained which shows that 0.66 tCO_2eq/ha per year of GHG emissions are generated in the management of biogas maize fields with agricultural machinery.

Table 3.2.

Fuel CO_2eq emission indicators per 1 ha of biogas produced from specially cultivated maize

	CO_2 emissions, kgCO_2eq/ha	CH_4 emissions, kgCO_2eq/ha	N_2O emissions, kgCO_2eq/ha	Total emissions, tCO_2eq/ha
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 + shredding to prepare maize for placing in the bioreactor, as well as due to compaction. The lowest emissions occur during sowing.

As a result, the highest emissions per ha are caused by the use of fuel to perform all the necessary treatment operations with heavy machinery, which is almost 0.66 tCO_2eq/ha (see Table 3.3). Emissions from tillage with nitrogen fertilizers and crop residue incorporation in soil after harvest are relatively similar, amounting to 0.468 tCO_2eq/ha and 0.443 tCO_2eq/ha. In total indicative emissions from biogas production from specially grown maize creates 1.567 tCO_2eq/ha.

Table 3.3.

Total indicative emissions from biogas production from specially grown maize per ha

Fuel emissions, tCO_2eq/ha	Crop residue emissions, tCO_2eq/ha	N fertilizer emissions, tCO_2eq/ha	In total, tCO_2eq/ha
0.656	0.443	0.468	1.567

The biogas production process produces a very valuable by-product – digestate. It contains significant amounts of nutrients that are suitable for enriching the soil [276]. The dry weight of digestate from biogas production using only maize is approximately 58.22 % [277]. Digestion of fields with digestate can indirectly reduce greenhouse gas emissions, for example, digestate from 1 ha of maize green matter with a yield of 30 t/ha fully provides the required amount of potassium fertilizer and saves 31 % phosphorus and 44–45 % nitrogen fertilizer [278].

Accordingly, using a maize yield of 31.8 t/ha, it is possible to provide fertilizer for 1.06 ha of maize. As a total of 25 700 ha of maize was grown in Latvia in 2017, the use of digestate is topical, as well as interviews with farmers conducted within the framework of this study revealed that unfortunately digestate for field fertilization is a shortage product, which is why additional synthetic fertilizers are used [279],[280].

Using digestate fertilizer in tillage, 1.19 $ktCO_2eq$ emissions were saved in 2017, while indicative emissions show a reduction of 0.22 tCO_2eq/ha (see Table 3.4).

Table 3.4.

GHG emissions saved due to digestate fertilizer

Harvested area, ha	Possible to fertilize, ha	Necessary nitrogen fertilizer emissions, $ktCO_2eq$	Potential nitrogen savings, %	Saved nitrogen emissions due to maize digestate in 2017, $ktCO_2eq$	Saved nitrogen emissions due to maize digestate in 2017, tCO_2eq/ha
5382.00	5704.92	0.0004683	-44.50	-1.19	-0.22

Although the use of digestate in field fertilization reduces emissions compared to synthetic fertilizers, digestion of soil with digestate also generates GHG emissions. The results of analyzes obtained from a farm producing biogas from maize indicate that the N content of the digestate fertilizer is on average 3.8 kg/t. Assuming that the maize harvest in 2017 is 171 147.6 t and that the amount of digestate from the amount of mass fed to the bioreactor usually ranges from 90 to 95 %, in 2017 158 311.53 t of maize digestate were obtained, while knowing the N content of digestate per 1 t, it is obtained that the total N per 5382 ha of the whole maize area was 0.60 kt [281]. Based on the level 1 methodology of the 2006 IPCC guidelines, it is estimated that digestate fertilization caused 2.82 $ktCO_2eq$ emissions in 2017 indicating on indicative emissions – 0.0005 tCO_2eq/ha.

The methane content of biogas produced exclusively from maize silage is known to be 52 %, and the biogas yield per ton of maize is 202 cubic meters, which allows to calculate both the total amount of biogas produced from maize harvested in Latvia, which is 34 571 815.2 m^3 from 171 147.6 t maize [282].

At a 1 % biogas leak in its production process in 2017, 2.63 $ktCO_2eq$ GHG emissions were released into the atmosphere (see Table 3.5).

Table 3.5.

Summary of GHG emissions from biogas production leaks

	1% emission losses	
	$tCO_2eq/year$	tCO_2eq/ha
CH_4	2.490	0.463
CO_2	0.139	0.026
In total	2.629	0.489

By making the calculations from the obtained data, which is calculated in Table 3.6, it shows a reduction of 11.92 tCO_2eq/ha per year by using specially grown maize for biogas production in Latvia's conditions.

Table 3.6.

Indicative CO_2eq emissions in 2017
from biogas production losses according to the principles of a scientific article [283]

Emissions from maize production, tCO_2eq/ ha year	CO_2 absorbed by maize, tCO_2eq/ ha year	Emission losses from biogas production (1%), tCO_2eq/ ha year	Emissions saved due to digestate, tCO_2eq/ ha year	Digestate fertilizer emissions, tCO_2eq/ ha year	Result, tCO_2eq/ ha year
1.61	14.32	0.49	-0.22	0.52	-11.92

The visual representation of the calculation principle of the carbon balance for biogas produced from specially grown maize is showed in Figure 3.1.

Fig. 3.1. Visual representation of the carbon balance, tCO_2eq/ha year.

3.2. sSWOT analysis results to evaluate the future of biogas in Latvia

Based on the obtained literature review, a table for sSWOT (sustainability Strengths, Weaknesses, Opportunities and Threats) analysis was created accordingly (see Table 3.7), in which the strengths, weaknesses, opportunities and threats were defined in the context of sustainability to shed light on the recent evaluation of Latvia's biogas sector.

Table 3.7.

Compiled aspects for sSWOT analysis

Strengths	Weaknesses
- Great deal of experience and knowledge has been accumulated; - Developed biogas sector, major investments have been made in existing equipment; - Extensive and highly developed agricultural sector.	- The potential of biogas is not fully exploited; - Negative public opinion and perception of biogas due to previous experience with the Mandatory Procurement component; - Major investments are needed in biomethane treatment and compression equipment; - Uneven distribution of stations in the regions of Latvia; - Impact and sustainability assessment of each biogas plant is needed.
Opportunities	**Threats**
- Reduce emissions from the energy sector, including transport sector; - Reduce agricultural sector emissions and pollution; - Opportunity to make full use of by-products; - Opportunity for Latvia to meet all climate goals; - To promote the involvement and interest of regions and companies in cooperating in the development of a single, effective system.	- In the future, the bioeconomy will increasingly develop, taking over part of the stock; - Reduction of financial support for biogas production; - Strengthening biogas production criteria; - Human factor in operational control mechanisms.

The summarized aspects show that the sector is already facing various difficulties and future threats due to the forthcoming change, but it has no less strengths and opportunities. Looking at the strengths, it is clear that biogas production is especially suitable for Latvia due to its developed agriculture. The biogas sector in Latvia is also developed, large investments have already been made in it both on the part of companies – producers and on the part of the citizens of the country, purchasing renewable energy produced from biogas in cogeneration plants for higher price. This is a testament to the extensive knowledge and experience already gained. But at the same time the sector has acquired a bad reputation and attitude among the citizens due to the conditions of the disorderly mandatory procurement component, causing great resistance and suspicion among energy consumers, who are no longer willing to support the sector financially. And as the potential of biogas has not been fully exploited, the transition from cogeneration to biomethane production will again require significant investments. Since there are many, but relatively small power stations in Latvia, which are unevenly distributed throughout the country, the question remains, whether it is planned to build treatment and compression equipment separately for each small biogas plant. It is not yet clear, how to do this more effectively, as no impact and sustainability assessment has been carried out for each biogas plant to understand, how smart it would be for stations to promote the change.

Whereas the transition to biomethane will require new knowledge of the operation of the stations, one of the risks is the possible errors made by the human factor, which would delay and hinder proper production and resource management. It must also be kept in mind that the bioeconomy is likely to develop rapidly in the future, which could possibly take over some of the raw materials from which higher value-added products would be produced. However, given that legislation have been adopted to strengthen biogas production criteria while reducing financial support for electricity produced in cogeneration plants from biogas, switching to biomethane production, seems an opportunity to save the viability of the biogas sector in Latvia and help to meet the climate goals by reducing emissions in energy, transport and agriculture sector and pollution, making full use of by-products. While unreasoned and short-sighted management could be the next threat to the industry, smart management could at the same time encourage the involvement and interest of regions and companies in working together to create a coherent framework for a well-designed strategy for smart investment, financial autonomy, and independence, which leads to an affordable product.

The results obtained using the sSWOT analysis can be used not only at the level of the company, but also at the level of the country, in order to make a theoretical summary of the conducted literature analysis on the current issue in the context of sustainability, but the results may change depending on events in the country and the world as a whole.

3.3. Multi Criteria Analysis results

3.3.1. Ranking of the most suitable bioresources for sustainable biogas production

After the TOPSIS methodology calculations were made, a rating was obtained of which, according to the accepted 3 criteria (environment, technology, economic), indicates where the given substrate is ranked from the most suitable substrate for biogas production in Latvia. These substrates were ranked from the best (1st) to the worst (8th) substrate from this list and shown in Table 3.8.

Table 3.8.

The feedstock rank determined with the TOPSIS method

	Place in the rank
Pig manure	1
Poultry manure	2
Straw	3
Cattle manure	4
Sewage sludge	5
Organic waste	6
Maize silage	7
Wood	8

Pig and poultry manure were ranked in the first two places according to the criteria, while straw with pre-treatment was ranked 3rd. Cattle manure was ranked 4th, but sewage sludge ranked 5th. The last 3 places are organic waste, maize silage and wood, which took a convincing last place in the ranking (see Fig. 3.2).

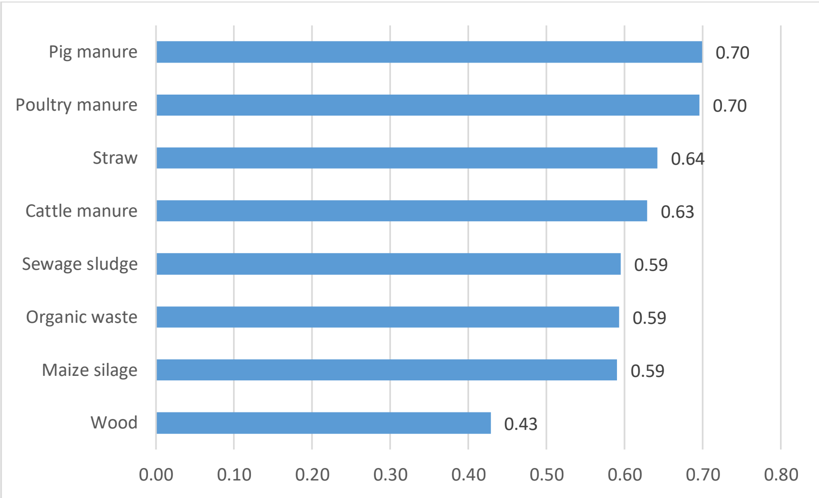


Fig. 3.2. The relative closeness to the ideal solution with TOPSIS method for biogas production.

The Figure 1 shows that the raw materials are basically divided into 4 groups according to the suitability of the substrate for biogas production:

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

3.3.2. Sustainable biogas application to energy sector

During the research, considering Latvian conditions, two scenarios found to be sustainable for biogas application in energy sector (see Table 3.9).

Table 3.9.

Designation of biogas application scenarios

Designation	Biogas application
Scenario 1	Combustion in CHP unit, when the produced electricity is further used in transport sector
Scenario 2	Production of biomethane, when it's further used in transport sector

The results obtained from evaluation of scenarios using TOPSIS showed that biogas upgrading and use of biomethane as transport fuel is the optimal solution for Latvia and has the highest Relative Closeness to the Ideal Solution (Ci). The results of multicriteria analysis are showed in Figure 3.10.

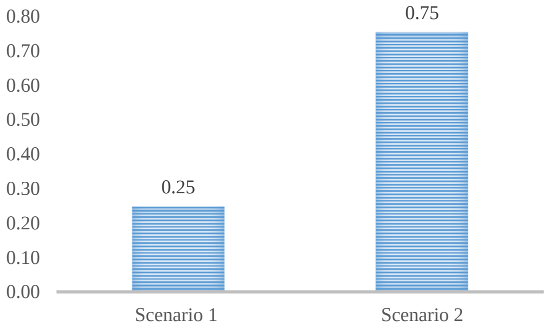


Fig. 3.10. The relative closeness to the ideal solution with TOPSIS method for biogas application.

The results show that the biogas upgrading to biomethane and its further use in transport sector as a transport fuel has 3 times higher suitability rating than biogas combustion in combined heat and power units to use the produced energy in the transport sector also as a transport fuel for electric vehicles.

3.3.3. Most suitable Carbon Farming methods

During the analysis of the literature, 6 possible carbon farming methods were selected, which could be applied to Latvian conditions and would be in accordance with Latvia's National Energy and Climate Plan. The choice was based on the European Commission Report about Sustainable Carbon Cycles and Latvia's Common Agriculture Politics (CAP) Strategic Plan. These methods can also be used in other countries with different levels of agricultural development.

In this article zero and minimal tillage was mentioned as one of the solutions, as it would mainly work as a method to reduce emissions due to significantly reduced diesel consumption and mineral fertilizers. Carbon sequestration with soils was considered and perennial plant cultivation in order not only to capture carbon but also store it. Whereas biogas production is already existing, but an effective method of preventing agricultural waste emissions and producing a valuable and safe fertilizer. However, biogas development into biomethane is essential to maximize added value and prevent also other sectors (such as transport) emissions as discovered in the previous research of suitable biogas application opportunities. The agroforestry sector is suitable for smallholder farms to increase carbon sequestration and storing in both soils and trees, reduce resource consumption and thereby emissions, and increase income, however, it must be in line with the foundations of biorefineries and focus on the efficient use of resources to achieve environmental, economic, and social goals. These methods are theoretically proving to be sustainable farming methods, which could possibly be introduced with funding for carbon farming, to ensure not only environmentally sustainable management in the future, but also the economy, to reduce costs and maximize local agriculture sector competitiveness.

The final rank for the most suitable carbon farming methods in Latvia are collected and presented in Table 3.10.

Table 3.10.

Final Rank for Carbon Farming method potential

Final Rank	Carbon Farming Method
1	Capture by soils
2	Biomethane
3	Perennial plants
4	Biogas
5	Zero tillage
6	Minimal tillage
7	Agroforestry

The TOPSIS analysis results confirm that by current area, budget, and environmental effectiveness, the biggest potential is for such Carbon Farming methods as capture by soils and biomethane, but the most unsuitable solution in Latvian conditions would be the development of agroforestry (see Fig. 3.11). Minimal tillage and zero tillage as carbon farming solutions also show not very high results.

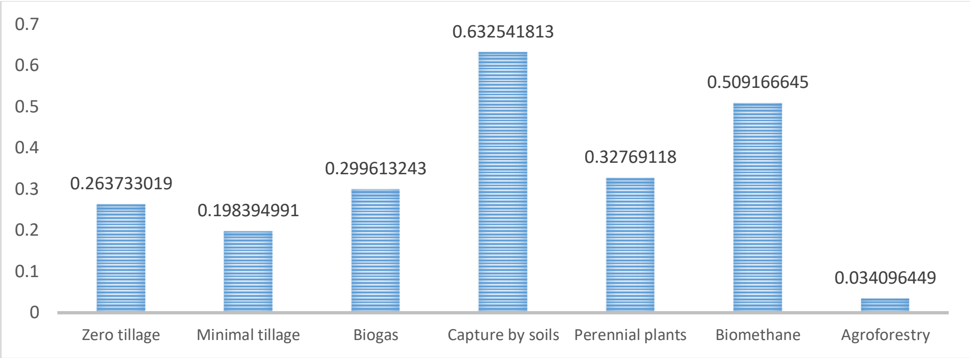


Fig. 3.11. The relative closeness to the ideal solution with TOPSIS method for carbon farming methods.

3.4. The role of energy management in agriculture

A significant part of GHG emissions in Latvia comes from agricultural lands and cattle's intestinal fermentation, which is why, in this work, measures of GHG reduction are explicitly proposed in these areas. GHG reduction measures are described in the "Guide for Farmers to calculate GHG at farm level and measures to reduce it." This guidebook is based on the IPCC guidelines, and this advice can be implemented in the case of Latvia. Some of the measures are introduced in the surveyed companies.

As the literature survey shows, a significant amount of emissions comes from land cultivation. The division of produced GHG emissions in both areas is as follows:

Agricultural land:

- implementation of precise fertilization system – plan development and required technique purchase – perform soil analysis;
- use of practical techniques and technologies – combined field processing machines, zero or minimal tillage technique implementation;
- land reclamation or improvement;
- trenches around the cultivated land to avoid water pollution by fertilizers.

Intestinal fermentation:

- nutrient dosage management (plan developed and introduced);
- nutrient additive utilization to improve digestion;
- purchasing cattle that produce less methane (CH_4) in their metabolic processes.

It is worth noting that the emission division in the agricultural sector emissions does not include the emissions from transport utilization and maintenance. In the Latvian agricultural sector's emissions, fuel produces only 11 % of the total GHG emissions [40]. This percentage would decrease if the proposed agricultural land and intestinal fermentation management measures were implemented.

Five company-level measures were identified by reviewing scientific articles and examining practices in this field of research. The most effective energy efficiency measures for the company level were determined:

- optimized fertilizer production;
- energy-saving cultivation practices;
- improved water management;
- better livestock feeding;
- use of renewable energy sources.

By introducing these measures, the emission level, the consumed energy, and resources, also expenses can be reduced. During the research, an energy management system (Fig. 3.12) for the agricultural sector at the company level was developed, which can be adapted to evaluate and compare different agricultural companies.

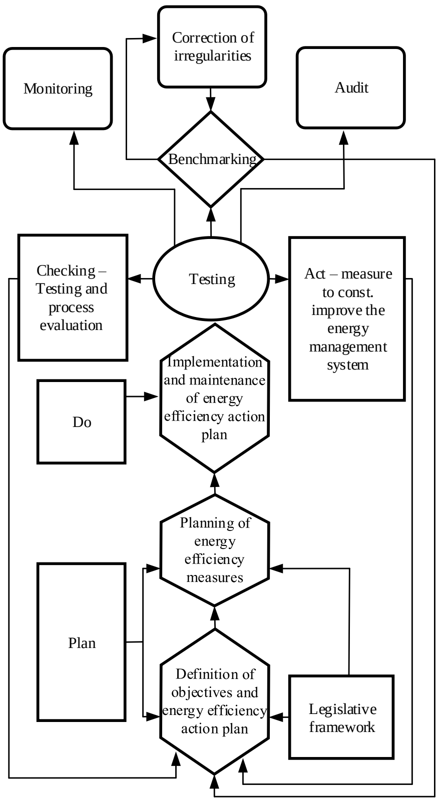


Fig. 3.12. Energy management framework for the agricultural sector on the company level.

The results have shown that using proposed indicators and benchmarking for farm comparisons is beneficial for improving the agricultural sector and reducing greenhouse gas emissions and energy consumption, leading to efficient, sustainable, and competitive farming.

3.5. The importance of resource efficiency and product production with higher added value in agriculture

The baseline scenario's outcome is represented by the flows taken from statistic databases and used as input data for the model with a correct mass balance. The bioresource flows for the base year 2015 are revealed in the Sankey diagram (Figure 3.13). The amounts of material input criteria are fixed to show a historical perspective of the livestock sector. This shows that the biggest part of the obtained animal products in mass units consists of locally produced and imported milk, locally produced meat, and eggs. Wool and honey obtained in the examined mass units make up a small part of the total volume of animal products. The largest part of the milk and food produced from milk is exported, and a noticeably big part of the products produced is used for local consumption with some losses (mostly from milk production).

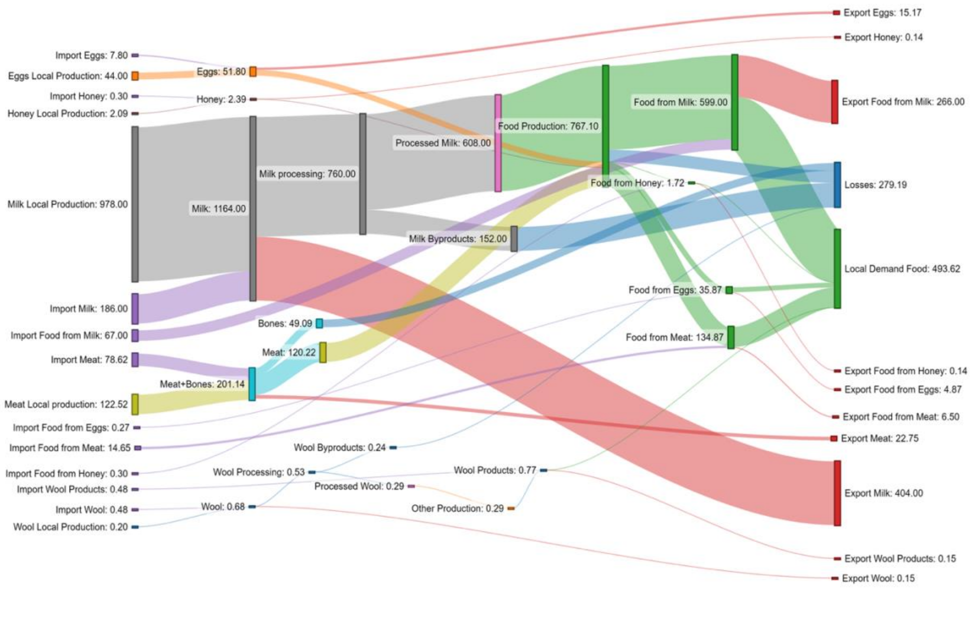


Fig. 3.13. Sankey diagram for the base year results (2015) in thousand tons, kt.

Even after introducing new technologies, the desired result of the complete use of by-products has not been achieved yet in any scenario because of local market limitations. However, it can be observed that trends calculated by the model show an increase in local and imported commodity volumes in 2023 and 2030 compared to the base year 2015 while having a decrease in total material losses. Although only part of the by-products was used in the production of the new products, their economic contribution over the 7-year period is noticeable. When introducing new technologies, the cumulative added value is calculated to exceed the set goal of a 30 % added value increase in bioresources in 2030 by more than two times (62 %) in years 2023–2030 in the case where these technologies are introduced starting in 2023 (see Figure 3.14).

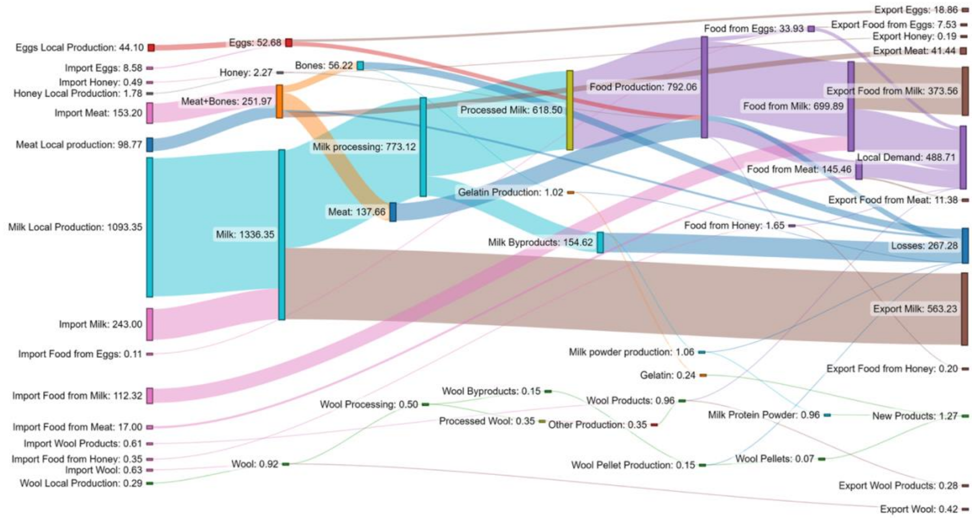


Fig. 3.14. Sankey diagram for the results of year 2023 in thousand t, kt.

Similarly, a Sankey diagram for 2030 with the results of the simulation, including data added on new products (gelatin, wool pellets, milk whey protein powder, and eggshell powder), is shown in Figure 3. The graph shows that flows for both domestic milk production and imported milk will increase, which are the largest flows, still followed by imports of imported dairy food and meat production. The by-products generated in the milk processing process are almost constant, which is the main source of by-products, but due to the new products, the total resource loss decreases by 33.9 kt. The final food flows show that the volume of exported milk has increased by 1.6 times compared to 2015, while food produced from milk has increased by almost 1.9 times. Other flows have also grown significantly, for example, exported meat by 2.7 times, exported wool and its products by 3.1 times, and exported eggs and their products by 1.7 times, but these flows are smaller against the overall background in mass units.

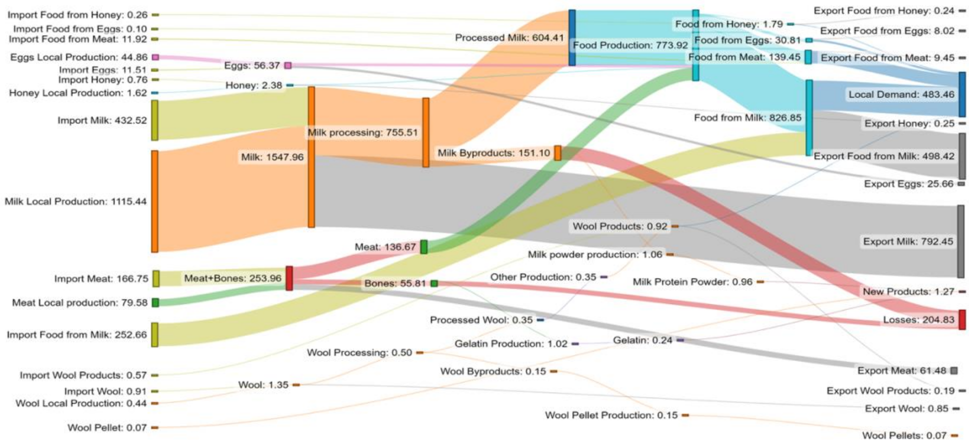
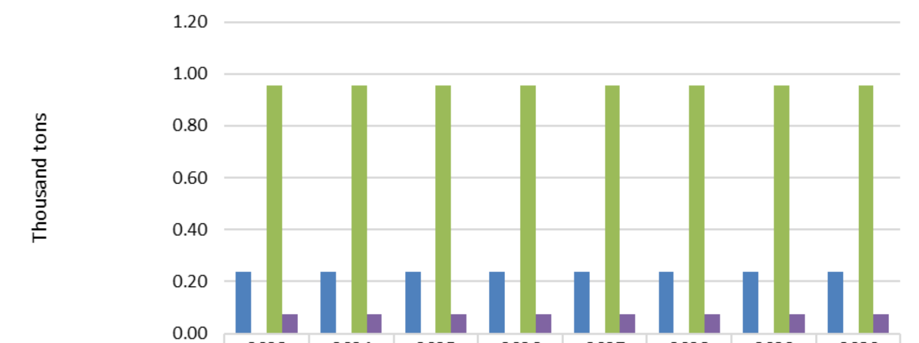


Fig. 3.15. Sankey diagram for the results in target year (2030) in thousand t, kt.

Among the new products, the model results show produced milk protein powder, gelatin, and wool pellets (see Figure 3.16) but no eggshell powder. The production of the new products is influenced by the efficiency and cost of the production processes and the added value per unit because the eggshell powder has a relatively low production efficiency due to the mass ratio and relatively high losses when the powder is produced from a whole egg.



	2023	2024	2025	2026	2027	2028	2029	2030
Gelatin	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Egg Shell Powder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Milk Protein Powder	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Wool Pellets	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074

Fig. 3.16. Number of new products produced, kt.

The model reaches the limits (e.g., the capacity of resource application, economic viability, and demand limit) of available resources for milk protein powder and gelatin; thus, the same amount is produced every year. Protein powder and gelatin reach the available resource limits immediately in 2023, and, therefore, their production is constant. As for the wool pellets, all of the wool resources available are used to produce wool pellets. The forecasted demand for pellets, on the other hand, is 58.37 thousand tons. The pellets produced are only about 0.1 % of this demand value. If forecasted demand values were removed, then all added value would be covered by milk protein powder.

Value added from new products as a share of total value added in different years ranges from 7.6 % to 8.2 %. On average, the added value is 7.9 % per year. This percentage changes as the number of other products produced changes from year to year, but the number of new products produced remains the same each year (see Figure 3.17).

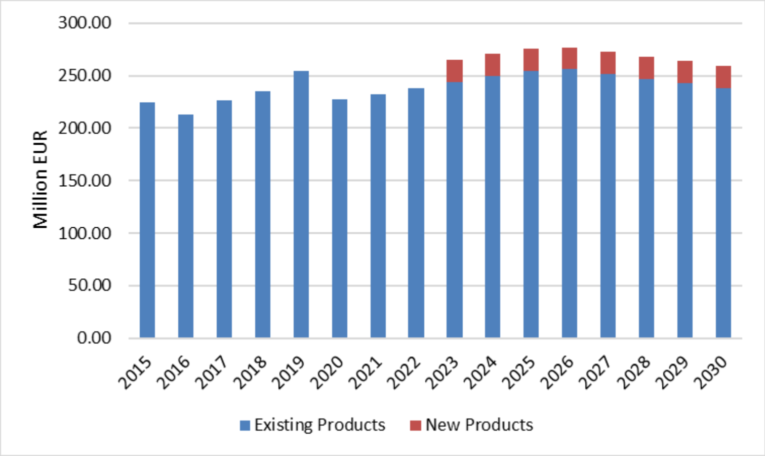


Fig. 3.17. Total existing and new product added value, EUR million.

Figure 3.18 shows the added value for newly produced added-value products. In this case, milk protein powder takes up most of the value added, which is probably since milk products constitute the largest share of food products and the added value per unit of milk protein powder is larger than that of other products.

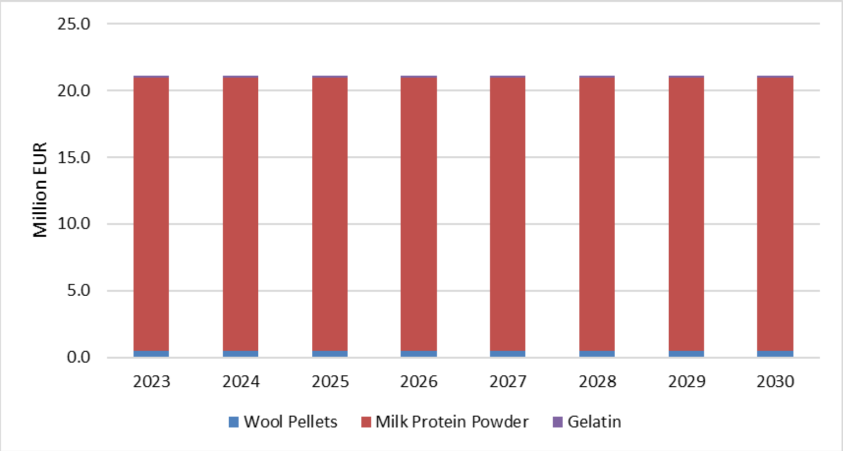


Fig. 3.18. Added Value Structure for newly produced added-value products.

3.6. Agriculture sector's transition towards Climate neutrality

By the calculations based on the data of the dairy company, it was found that it is possible to achieve several improvements by investing.

By building a new barn, the company:

- reduced electricity consumption by 7000 kWh/year, which is a 46 % reduction;
- increased milk yield from one cow by 2129 kg/cow/year, which is a 25 % improvement compared to the year of making the investment;
- increased milk yield from one cow by 3987 kg/cow/year, which is a 42 % improvement, compared to the 10-year average milk yield before the investments.

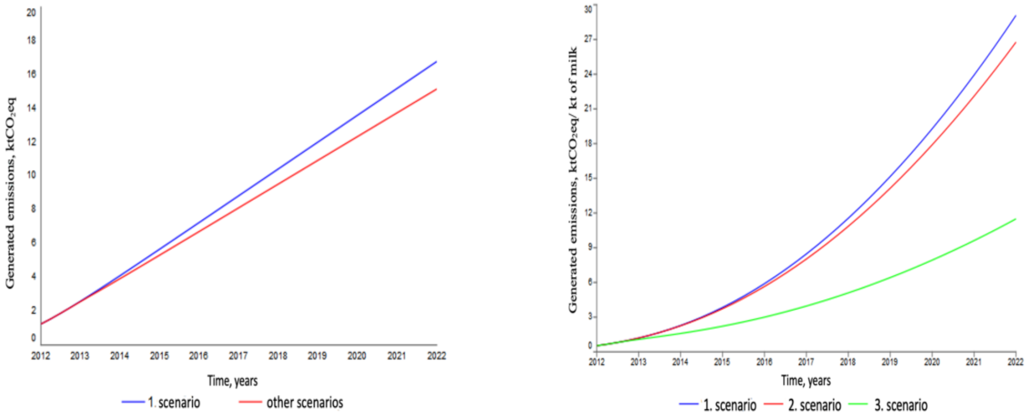
By investing in feed feeding technologies, the company:

- increased milk yield by 174 kg/cow/year, which is a 2 % improvement compared to the year of making the investment.

From the system dynamics model, it was determined that the generation of emissions in both the first and second scenario is characterized by a linear curve (Figure 3.19a). The number of generated emissions increases every year as the number of cows increases, which thus increases the number of emissions generated from intestinal fermentation processes. However, because of the introduction of innovations, it is possible to observe a reduction in emissions, as a higher level of manure management reduces emissions from manure.

When comparing the emissions created in these scenarios, 2017 and 2022 were taken as reference points, and it was determined that with the help of the 2nd scenario, compared to the first scenario, emissions are reduced by 0.1 % in 2017 and by 10 % in 2022.

Then, the generated emissions per produced quantity, which is the most essential and objective indicator in agriculture, was examined. Figure 3.19b shows the emissions per produced amount of production, which is measured in ktCO_2eq/kt of milk produced. In general, it can be observed that the 1st scenario also produces the highest emissions for the production, while the 2nd scenario produces less emissions than the 1st scenario only from 2015, but in the 3rd scenario, significant changes can be observed compared to the other two scenarios.



(a) (b)

Fig. 3.19. (a) The total amount of emissions produced in several scenarios; (b) The total amount of emissions generated per the amount of output produced in several scenarios.

When comparing the generated emissions between the scenarios, 2022 was taken as a reference point. It was found that by implementing the second scenario (when investments only in manure management technology development are made), compared to the first scenario (when no improvements are made), it is possible to achieve a reduction in emissions by 8 % (2.32 $ktCO_2eq$/kt of milk) in 2022.

When comparing the generated emissions between the second scenario (where improvements only in manure management are made) and third scenario (where improvements in manure management, thermoregulation and feed improvement are made), it was found that by implementing the third scenario, it is possible to achieve a reduction in emissions by 57 % (15.28 CO_2eq/kt of milk) in 2022.

When comparing the generated emissions between the first scenario (where no improvements are made) and third scenario (where improvements in manure management, thermoregulation and feed improvement are made), it was found that by implementing the third scenario, it is possible to achieve a reduction in emissions by 60 % (17.59 CO_2eq/kt of milk) in 2022.

The increase in the number of cows occurs up to and including 2016, but remains constant thereafter. Comparing the year 2013 with the year 2022, it can be determined that the number of cows has increased by 23 %.

The initial milk yield per cow was 6.377 t/cow, which remains unchanged in the first and second scenario, but in the third scenario, it is possible to observe an increase in milk yield in the maximum average milk yield per cow, which is 15.870 t/cow per year. Comparing the first year of the third scenario with the last one, it is possible to observe an increase of 69 % (5261.45 t more), but comparing the third and first scenarios of 2022, it can be concluded that by investing in the improvement of the farm, it is possible to achieve a 60 % higher amount of production, which is 4550.99 t more (Figure 3.20).

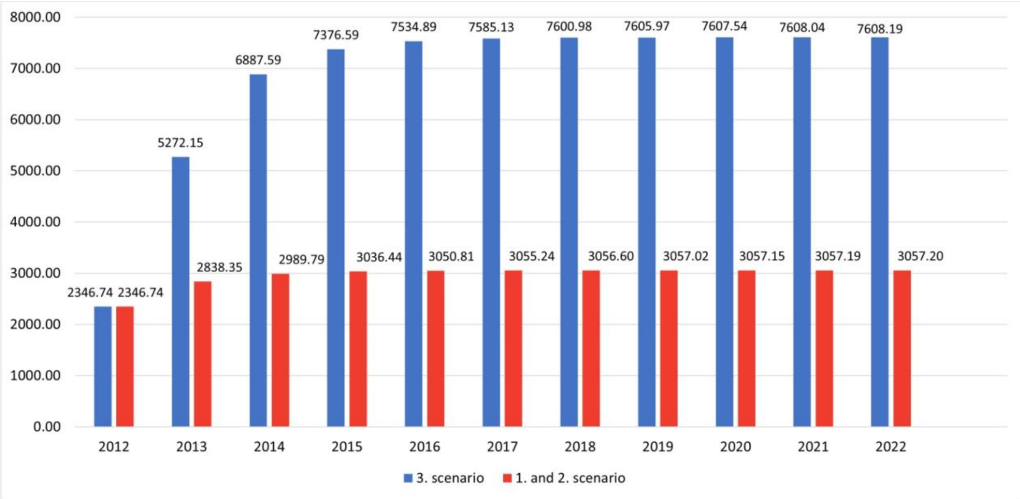


Fig. 3.20. Milk production in the first, second, and third scenarios.

4. SUMMARY OF THE RESULTS AND DISCUSSION

1. Carrying out carbon balance based on life cycle analysis for assessment of the impact of biogas production from a certain resource, it is possible to determine the environmental impact in terms of GHG emissions.

2. The carbon balance gives the opportunity to analyze the emission sources and their impact to improve the balance by reducing these emissions, however, it is essential to combine efficiency in agriculture to reduce atmospheric emissions without losing sight of sustainable farming, so as not to have a negative impact on soil, water, and the environment.

The research of carbon balance proves that by its novity – carrying out carbon balance by the methodology based on life cycle analysis for assessment of the impact of biogas production from maize, it is possible to determine the environmental impact in terms of greenhouse gas emissions on the atmosphere. Despite the consumption of diesel fuel and emissions from the maize production process, maize absorbs much more carbon than is produced during photosynthesis, thus, if 1 % of biogas leakage is assumed in its production process, as well as knowing by previous calculations that 34 571 815.2 m^3 of biogas can be obtained from 5382 ha specially grown maize, its production from specially grown maize can save 1.86 kg CO_2 eq emissions per 1 m^3 of produced biogas.

There are several possibilities in which the carbon balance can be further improved by reducing emissions from the agricultural process by growing the substrate, for example, using zero-emission electric tractors for soil tillage, could reduce total biogas maize growing emissions by 43 %. But there are also processes that would not be desirable to reduce emissions, for example, the tractor driving frequency reduction in the field - the fertilization process can theoretically be carried out immediately and at once, but fertilization is divided into several stages in order to gradually spread the substances for a favorable plant vegetation process, as well as not to promote pollution of water due to drainage that leads to erosion . After harvest, 28 % of total emissions come from nitrogen emissions from crop residues (above and below ground). Unfortunately, these are emissions that cannot be reduced because, although these residues could theoretically be used for biogas production, the removal of crop residues from maize fields would have a negative impact on the environment and soil quality. It is essential to combine efficiency in agriculture to reduce atmospheric emissions without losing sight of sustainable farming, so as not to have a negative impact on soil, water, and the environment.

3. Biogas transition from cogeneration to biomethane production is a way to maintain the viability and sustainability of the industry, at the same time it means facing economic, social and technical challenges.

Regarding the transition of biogas from cogeneration to biomethane, because of current decisions, seems to be a way to save the viability and sustainability of the sector. At the same time sector faces the challenges of:

- reaching maximally efficient and smart system that involves biogas producers and regions in planning investments;
- being as financially independent as possible in the future;
- changing the negative public opinion and perception;
- bioeconomy development, which may take over part of the stock;
- achieving maximum resource efficiency;

- playing its full role on the way to climate neutrality and reducing agricultural, transport and energy sector greenhouse gas emissions;
- critical assessment of the sustainability and resource availability, the possible way of selling the product for each biogas plant.

4. Use of any waste for (at least) energy production is important, but pig manure and poultry manure are the most suitable raw materials for biogas production in Latvia, especially if combined with straw or other plant biomass by-products.

To meet some of these challenges and achieve maximum resource efficiency in the context of Latvia, a multi-criteria analysis using TOPSIS methodology was made taking into account 3 main parameters: economic feasibility, substrate efficiency and environmental friendliness. It showed that pig manure is the most suitable raw material for biogas production in Latvia, while poultry manure was ranked second, with very little difference in value from pig manure. Despite the claim that lignocellulose rich plants are not a successful choice for biogas production, straw was the third best substrate for biogas production in Latvia, while in the 4th place was cattle manure. In the last place, wood was identified as the most unsuccessful choice for biogas feedstock. The penultimate place in the ranking was for specially grown maize for biogas production, which until now has been a popular substrate for agricultural biogas production. Based on the criteria used in the model, the organic waste and sewage sludge are roughly the same as biogas maize in the rating. This work proves that pre-treatment straw can serve as a great substitute for biogas maize. The use of any waste for energy production is important, but the greatest potential shows in agricultural biogas production from combining manure and straw.

5. Biogas application to biomethane production is more effective and more sustainable solution for the energy sector that biogas combustion in CHP unit.

During the biogas application in energy sector research, the sustainable application of biogas for energy sector was evaluated. The study examined the case of biogas used in cogeneration plant and electricity produced in cogeneration for auto transport versus the conversion of biogas into biomethane for the use of auto transport. Latvia was used as a case study in this research. The research shed light on sustainability aspects of biogas production and use in future and on how the renewable energy applications can move forward in Latvia. TOPSIS method was used to evaluate two scenarios: 1) biogas production and cogeneration in CHP unit and use of electricity produced in CHP unit for the auto transport; and 2) biogas upgrading to biomethane and use of it for the auto transport. The results show that biogas application to produce biomethane is the best and more sustainable solution.

6. The biggest potential for Carbon Farming methods in Latvia are: carbon capture by soils, biomethane production and planting of perennial plants, while agroforestry turned out to be the least suitable method to Latvian conditions.

The study of carbon farming solutions also confirmed the need for and importance of including biomethane in the strategy of climate-neutral agriculture. The TOPSIS analysis results confirm that by current area, budget, and environmental effectiveness, the biggest potential is for such Carbon Farming methods as capture by soils, biomethane, and perennial plants. As biomethane production is most directly related to biogas production, as well as zero tillage and minimal tillage to carbon capture by soils, it reaffirms that all these methods are interrelated and important for moving towards sustainable agriculture. Agroforestry in Latvian conditions got the lowest compliance in this rank; however, perennial plants received a relatively high-ranking place. These 6 subjectively selected carbon farming methods, but also calculations can be used in other countries with different levels of agricultural development. Since the calculations were made based on assumptions from scientific publications, it is recommended to reconstruct these estimates using accurate data if available.

7. Carbon Farming cannot ensure complete climate neutrality of the agricultural sector alone, as mostly it focuses on field crop production, so it is important to develop resource and energy efficiency, which is possible to implement in every agricultural enterprise.

However, such solutions cannot ensure complete climate neutrality of the agricultural sector; as the types of agriculture are numerous and very diverse. It is important to view the entire system in its entirety, including all elements and methods to achieve the best result, and it is unimaginable without resource and energy efficient management, where no more is spent than necessary. The energy management system can and should be implemented by agricultural companies. It would reduce energy consumption, optimize costs, and reduce GHG emissions. However, informative measures are required to implement these basic energy management principles in companies. The companies should follow the initial monitoring of energy consumption data to understand where electricity and heat are consumed the most and the potential for reducing this amount. It would be advisable for agricultural companies to install an intelligent energy system. It is a sustainable energy supply system that contains information on energy consumption and options for reducing it based on monitoring the system's performance. The energy management system can be combined with greenhouse gas reduction measures, such as organic farming and other methods and guidelines already introduced in Latvia. However, not all companies follow these guidelines. It is necessary to develop a specific policy and support program for companies to implement energy management, as implementing the basic principles of energy management or the energy system requires investment. By implementing the energy system in an agricultural company, energy consumption in this company can be assessed, and measures can be taken to reduce energy consumption. Policy and agricultural guidelines should focus on optimizing farming and manure management. Results from the research show that energy efficiency improvement measures are a more effective way to reduce CO_2 emissions. If measures are applied to reduce GHG emissions from the mixed agricultural companies, the average emissions would be reduced by 43%. By implementing the basic principles of energy management, it would be possible to reduce the average energy consumption by 17 % in the studied companies. However, it depends on the specifics of the company and what measures it can implement.

8. It is crucial to combine resource efficiency with the production of products with higher added value from the local agricultural by-products, because it would bring an outstanding contribution to both the company's and local economy.

9. The TIMES model makes it possible to evaluate aspects related to an increase in added value empirically with a time reference to find an optimal scenario for the development of the agricultural sector.

If it was found that it would be necessary to introduce energy efficiency measures in any company, then a study was carried out for resource efficiency too. This is very important, because when implementing various measures to move towards climate neutrality, a drop in productivity is possible, which reduces the company's income, so it is necessary to explore the

possibilities and importance of increasing the added value of resources in the agricultural sector. The study presents a novel model that helps to investigate the application of new technologies in the agriculture sector and evaluate their contribution to the agriculture sector in terms of the production of new competitive products and the development of biorefineries that have a significant impact on both agriculture and other sectors overall resource efficiency. The model shows that the production of local resources with a higher added value would bring a more outstanding contribution to the local economy. In terms of mass, however, the desired result of the maximum use of by-products was not achieved in any scenario. When introducing the new technologies starting in 2023, the local bioeconomy benefits strongly by producing higher-added-value products.
In this study, the evaluation of aspects related to biorefinery implementation is performed with the developed model in relation to the national bioeconomy goal set for a 30 % increase in the added value of bioresources by 2030. The new technologies introduced in the model that create higher added value from bioresources obtained in animal husbandry are the production of protein powder, gelatin, and wool pellets. The new technologies in the model are available starting in 2023 and are used in the production of added-value products. The cumulative added value produced from 2023 to 2030 is about 62 % above the added value produced by currently used technologies. However, the maximum use of bioresources has not been achieved due to assumptions limiting the production of new products in line with the market size for these products. The production of milk protein powder and gelatin reached the set market size limit. The production of wool pellets reached the maximum of what was possible given the amount of wool processing by-products. The remaining eggshell powder amount could potentially be decreased with higher eggshell powder production efficiency or higher added value for eggshell powder.
The model makes it possible to evaluate aspects related to an increase in added value empirically with a time reference to find an optimal scenario for the development of the agricultural sector. This can be useful for making agricultural stakeholders aware of the development of biorefineries and their positive impact on the local economy. The obtained optimal scenario can be used in national policy planning, as it clarifies which technologies are worth investing in and what agriculture residuals have the most potential to be used to produce higher-added-value products. Further research with statistical data from other sources and the introduction of more new technologies can be applied in the TIMES bioeconomy value model (TIMES-BVM) for defining more possible scenarios for the development of biorefining and development of suggestions for bioeconomy policy planning.

10. Agriculture is the sector, where energy and resource efficiency decisions should be looked at very carefully, because unprofessionally made decisions can not only threaten the existence of companies with productivity losses, but also harm the environment.

11. Regarding to animal husbandry, the strategic documents emphasize manure management and improvement of feed quality, but an important missing element is visible - a section on improving the thermoregulation of animals.

12. It should be noted that the larger the volume of production, the lower the number of emissions produced per unit of production. However, in agriculture, it is possible to achieve it mainly through investments in new, modern technologies.

13. The created system dynamics model allows both to understand and to model possible scenarios; to calculate not only the impact of a given company or sector on the environment by calculating the generated emissions per unit of production, but also to

calculate the investments required to reduce 1 kt of CO_2eq generated in the company. Such a model makes it possible to make sustainable decisions not only at the level of the company, but also at the level of state policy, to simultaneously promote environmental goals, economic growth, and the development of the national economy.

Finally, when answers to many topical questions have been obtained, it is important to look at the system as a whole and a dairy company was used for such inspection, which, in author's opinion, perfectly reflects the specifics of agriculture in the management of resources and energy – it is a huge responsibility, because living creatures live in it and not only their health, but also productivity depends on the decisions made. The other sub-sectors of agriculture should also be looked at in the same manner, because, as already revealed in the first study of this Thesis, agriculture is the sector, where energy and resource efficiency decisions should be looked at very carefully, because unprofessionally made decisions can not only threaten the existence of companies, but also harm the environment.

Regarding to animal husbandry, the strategic documents emphasize manure management and improvement of feed quality, but an important missing element is visible - a section on improving the thermoregulation of animals. All these elements (manure management, feed quality, and thermoregulation) are an integral part that must work in one system, because their improvement significantly improves productivity, reduce energy consumption, improves resource efficiency, and reduces direct and indirect emissions not only in agriculture, but also in the energy and transport sectors. It should be noted that the larger the volume of production, the lower the number of emissions produced per unit of production. However, in agriculture, it is possible to achieve it mainly through investments in new, modern technologies, because an ill-considered economy of energy or resources can result in yield losses, which would not be a sustainable solution at the company or at the state level. Agriculture cannot focus only on energy efficiency and greenhouse gas emission reduction without consideration of aspects such as the impact of the activities on yield, technology, free available funds, market stability, state support, and others. It is important to look at ways to increase productivity while introducing energy-efficient and resource-efficient methods - a thoughtful management model. Only that way would it be possible to achieve sustainability from both an environmental point, and also from an economic point.

However, such technologies require investments, which are directly affected by the company's income and savings, and in turn are affected by the volume sold and the price of the product in the market, support mechanisms, existing technological level, and efficiency. To ensure the sale of the product on the market at a sufficiently high price for the company to develop innovation, it is important to develop a national policy that guarantees sales of the local producer's products. This is very important, because if there is more support and protection for agricultural enterprises in competing countries, not only will the price be competitive, but the safety of selling the products on the market will also fall. Ill-considered local policy fails to promote opportunities for local producers' innovation development comparing to competing countries' companies. This is especially critical now, when adapting to climate change and trying to fulfill the Green Deal goals; failing to develop sustainable policies risks destroying the local market's ability to compete and exist. The created system dynamics model allows us both to understand and to model possible scenarios; to calculate not only the impact of a given company or sector on the environment by calculating the generated emissions per unit of production, but also to calculate the investments required to reduce 1 kt of CO_2eq generated in the company. Such a model makes it possible to make sustainable decisions not only at the level of the company, but also at the level of state policy, to simultaneously promote environmental goals, economic growth, and the development of the national economy.

CONCLUSIONS

1. By carrying out a carbon balance to assess the impact of biogas production from a certain resource, it is possible to determine the impact of this process on the environment in terms of GHG emissions, and such a carbon balance calculation provides an opportunity to analyze the sources of emissions and their impact to improve the balance by reducing emissions.
2. The calculation of the carbon balance for biogas produced from specially grown maize proves that the impact of biogas produced from possibly the most provocative raw material can be evaluated favorably in terms of GHG emissions, moreover, considering that approximately 6^{th} of all available manure resources per year in Latvia were used for the biogas production at the time of the study, it proves the currently underutilized potential of biogas.
3. The use of any residual products (at least) for energy production is important, but pig and poultry manure were determined as the most suitable raw materials for biogas production in Latvia, especially when combined with straw or other plant biomass by-products.
4. Transitioning the use of biogas from burning it in a cogeneration plant to the production of biomethane is a way to maintain the viability and sustainability of the biogas industry to promote the production of renewable energy in the agricultural sector from by-products from which it is not possible to produce other products with a potentially higher added value. Biomethane production could potentially have a positive impact not only on agriculture, but also on the transport sector, which is one of the largest GHG emissions sectors.
5. The use of the EU's carbon farming initiative is essential, given that it will be compensated in line with the development of new EU business models. Such a compensation system can potentially serve as an effective support mechanism mainly in field crop production, which would help in the transformation of agriculture towards more sustainable methods. However, at the time, it is very important for each country and company to evaluate the most suitable methods for them, including available soils and conditions. In the study, the suitability of various methods for the conditions of Latvia was determined according to several criteria, in which it became clear that the greatest potential of carbon farming in Latvia are various methods of capturing carbon in the soil, as well as biomethane production, while the most unsuitable is agroforestry.
6. Since carbon farming mainly focuses on field crops, it cannot be the only solution in moving agriculture towards climate neutrality. One of the most important practices is the implementation of energy efficiency management, which is possible in absolutely every agricultural enterprise.
7. It is essential to combine resource management with the production of the highest value-added products from local agricultural by-products, as this would contribute to strengthening the economy of both the company and the country. This is particularly important not only for the effective use of all available resources, but since during the

transition period from traditional agricultural methods to sustainable ones there is a possible decrease in yield, it is an opportunity to increase the economic benefit from existing resources.

8. The developed TIMES model makes it possible to empirically evaluate the application of new technologies in the agricultural sector to increase the added value through the production of new products with a higher added value and to find an optimal scenario for the development of the agricultural sector. The case study of animal husbandry proves that with the help of new technologies and using part of animal husbandry by-products that end up as losses, it is possible to increase the added value by an average of 7.9%, which could be increased by covering the export possibilities of the new products.
9. Agriculture is an industry where energy efficiency and resource efficiency decision-making should be developed very carefully, as unprofessional decisions can not only threaten the existence of companies with productivity losses, but also environmental damage.
10. Regarding animal husbandry, in the strategic documents, manure management and improvement of feed quality are especially emphasized, but after the case study of the dairy farm, an important missing element can be seen – a proposal for improving thermoregulation of animals, which is the main prerequisite for improving productivity.
11. It is important to consider that in agriculture it is crucial to look not at the emissions per company, but at the emissions per unit of production, which is the most objective indicator of the company's sustainability and progress towards climate neutrality.
12. In agriculture, the increase in productivity in accordance with the implementation of environmental measures can be achieved mainly with new, modern technologies, which require investments. However, for companies to be able to invest in new technologies and develop towards climate neutrality, it is important that favorable conditions are created so their products are competitive in the local and global markets, as well as the adoption of thoughtful political decisions.
13. The created system dynamics model allows both to understand and to model possible scenarios, to calculate not only the impact of a specific company or industry on the environment by calculating the generated emissions per unit of production, but also to calculate the necessary investments to reduce 1 ktCO_2eq generated in the company. Such a model provides an opportunity to make sustainable decisions not only at the level of the company, but also at the level of state policy, while promoting the achievement of environmental goals, economic growth, and the development of the national economy. The case study proved that with the help of investments in new technologies, it is possible to simultaneously move towards climate neutrality, reducing 60% of the generated emissions per ton of production, while increasing productivity.
14. The hypothesis was confirmed: effective progress towards climate-neutral agriculture is possible only if it is carried out in a comprehensive way, combining 3 main prerequisites: resource management, resource efficiency and carbon farming, as well as

parallel production of products with higher added value and/or non-reduced, preferably increased productivity.

15. To promote the successful progress of local companies towards climate neutrality and at the same time maintain their competitiveness in the market, the strategy determined by the state is very essential to guide the transformation of companies in a professional way, while the methodologies and models developed in the dissertation can be used for decision-making processes.

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What Will Be the Future of Biogas Sector?

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Abstract **– Latvia, like many other European Member States, faces major challenges in achieving climate goals within the Paris Agreement – emission reduction for 50–55 % by 2030 and net-zero emission economy by 2050. Decarbonization of the energy sector is one of the main aims and sustainable use of biogas is one of the ways to reach these targets. Although the biogas sector in Latvia is now mainly based on the production of electricity and heat in cogeneration plants, often using specially grown energy crops, and payments of the mandatory procurement component have expired, biogas plants are preparing for reconstruction for the production of biomethane with the help of European fund investments. It means that the biogas sector is moving towards a completely different operating model, based primarily on the management of agricultural waste as a feedstock, the conversion of biogas to biomethane and it is used mainly in the transport sector, but its implementation in practical terms faces various challenges. In this context, this article offers a clear vision of the development of the biogas sector in the next decade in Latvia. It uses a sustainability SWOT analysis to clearly reflect the sector's strengths, weaknesses, opportunities and threats.**

Keywords **– Biomethane; decarbonization of energy sector; emissions; SWOT analysis**

1. INTRODUCTION

The Intergovernmental Panel on Climate Change Special Report 'Global Warming of 1.5 °C' reflects the necessity to limit the rise in global temperatures to 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways to strengthen the global response to the threat of climate change, sustainable development and efforts to eradicate poverty [1]. This can be achieved by targeting all necessary actions to reach climate neutrality by 2050 [1]. On 12 December 2015, Parties to the United National Framework Convention on Climate Change (UNFCCC) made an agreement between all nations to fight climate change with the adoption of the Paris Agreement [2]. In November 2018, the European Commission presented its Long-Term Strategy for 2050 'A Clean Planet for All' for a prosperous, modern competitive and climate-neutral economy by 2050, which aims to establish a vision to implement the Paris Agreement [3]. The Green Deal, which was proposed in 2019, is a roadmap, for how to reach the newly set climate goal for 50–55 % emission reduction by 2030 and net-zero emission economy by 2050 [4]. It is a plan to make the European Union's economy sustainable by turning climate and environmental challenges into opportunities, where there are no greenhouse gas emissions by 2050 [5]. It provides an action plan to move to a clean, circular economy and cut pollution. The action plan to reach this target includes investing in environmentally-friendly technologies, supporting industry to innovate, decarbonizing the energy sector and other activities [5]. To reach the target to cut emissions in the EU by at least 40 %, increase renewable energy contribution for at least 32 %, member state countries were also required to develop national long-term strategies by

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1st January 2020 [6], [7]. Taking into account the outlined long-term development directions, Latvia's National Energy and Climate Plan (NECP) for 2021–2030 has been created, which determines the basic principles, goals and actions for Latvia's energy and climate policy for the next 10 years and the Strategy towards Climate-Neutrality 2050 [8]. A medium-term policy planning document has also been adopted, which covers all sectors of the economy and sets goals and directions for actions to promote economic growth for 2021–2027 - the National Industrial Policy Guidelines (NIP) [9].

To reach these targets practically, all scenarios recognize the importance of renewable energy development for the decarbonization of the energy sector. Renewable energy production will increase with a particular focus on solar panels and collectors, also wind energy, however it is clear that it will not be technologically possible due to the storage issues, which is why it would be very important to develop a gas-power network as well [10]. This could be a solution for sectors that would be problematic to electrify, for example, heavy trucks, tractors and other vehicles and machinery [11].

Decarbonization and gasification of the transport sector is currently the most topical issue for policy makers in Latvia, because, along with other EU Member States, Latvia has to ensure that the share of renewable energy in the final energy consumption in 2030 reaches 14 % (the target for this in 2020 is a 10 % share), but only 4.7 % were achieved in 2018 [12].

Gasification of the transport sector is at a very early development stage and the availability of second-generation biofuels is very limited due to technical development and lack of infrastructure [13]. At the same time, anaerobic digestion has been used for a very long time and it is a completely developed technology for the production of biogas from organic waste [14]. After biogas extraction, it has mainly two options for further use –combustion to provide heat and electricity at cogeneration plants or upgrading to biomethane to use it as a road fuel [15]–[17]. Both in Europe and in Latvia, the industrial use of biogas is based on power generation through combined heat and power units [18], [19].

Biogas production is particularly suitable for Latvia, because agriculture in Latvia accounts for 22.3 % of total GHGs, ranking as the 2nd largest GHG emitting sector [20]. At the same time, according to data sent by the Latvian Biogas Association, the situation with the actual number of operating biogas plants in Latvia is deteriorating, as many plants have been forced to close due to insufficient support, as well as political instability. Since 2016, when 56 biogas plants were in operation, 7 plants have ceased their operations by 2020. Moreover, in 2020 at least 5–6 more biogas plants stopped operating [19]. However, if the annual production of biomethane from anaerobic digestion in the European Union was 2.3 billion m^3, it is estimated that it could reach 64.2 billion m^3 by 2050 in the case of an optimized gas scenario.

Summarizing this information, it is clear that biogas industry needs to make major changes, so this article offers a clear vision on the development of the biogas sector in the next decade in Latvia. The research uses an innovative approach by mixing strategic literature review with sustainability SWOT analysis to clearly reflect the sector's strengths, weaknesses, opportunities and threats. It could serve as a document for policy makers to provide insight into how the biogas sector looks now and where it is heading with current policy guidelines and plans.

2. METHODS

This paper is a result of a strategic literature review, mainly analysing reports, legislation, scientific articles that were identified as a relevant material to provide an understanding of the recent evaluation of Latvia's biogas sector. The search was performed mainly using Google, ScienceDirect, Web of Science, Google Schoolar, following the example of the keywords used in the article for a similar purpose to reflecting a vision of European biogas sector development towards 2030 [18]. A combination of the following search requirements were used in the process of finding relevant information and articles: 'biogas', 'biomethane', 'Latvia', 'Green Deal', 'Paris Agreement', 'European Union', 'agriculture', 'greenhouse gas', 'plant', 'energy crops', 'cogeneration', 'upgrading', 'feedstock', 'legislation', 'infrastructure', 'gas', 'manure', 'renewable', 'strategy', 'production', 'energy', 'fuel', 'National Industrial Policy', 'guidelines', 'National Energy and Climate Plan', 'economic', 'efficiency', 'economic', 'technical'. The following three conditions were applied:

1. Priority was given to the most recent articles, when selecting sources of information;
2. Special attention was given to select papers for relevance, for example, national plans, technological and economic reports for Latvia's energy, biogas sector, journal articles to look objectively at the most pressing issues and developments from the last 20 years;
3. Scientific papers published in peer-reviewed journals in English.

This article mainly studies the development of Latvia's biogas industry, which is especially relevant and interesting due to its instability and rapid variability. The analysis sheds light on the economic, environmental, political and social dynamics through the application of a Sustainability SWOT (sSWOT) method. The sSWOT analysis is particularly suitable for assessing strategic sustainability management and clearly reflecting the strengths and opportunities of the industry, as well as weaknesses and threats, as only by clearly identifying them can them, a strategy can be developed to address these threats. Such analysis serves as a reference point that diagnoses the current situation, as well as the possibilities of the future scenario from a local perspective [21]. This approach, using SWOT analysis has been used by other researchers too, for example, in a research evaluating the introduction of sustainable renewable energy strategy in Pakistan [21].

3. LATVIAN BIOGAS SECTOR DEVELOPMENT

3.1. Biogas Production

The first research on biogas production appeared in Latvia already during the USSR, while in the early 1980s the first biogas plant was built near a pig farm [19]. Although the development of biogas production has been decreasing since 1991, already in 2009 58 entrepreneurs received a quota for biogas production with a total installed electrical capacity of almost 54 MW [19]. Consumption of biogas produced in 2017 increased to 80.73 MW (3.9 PJ) since 2014, reaching 25.81 % increase of biogas production [22].

Meanwhile, in 2018, a total of 18 202 biogas plants with a total capacity of 12.6 GW were operating in Europe, taking the position of a world leader in biogas production, far ahead the USA, which is in second place with a total capacity of 2.4 GW [23]. Although biogas production in Europe has developed significantly over the past 20 years, the biogas industry in Latvia has not stood out with stability and resilience, as evidenced by the information provided by the Latvian Biogas Association. Since 2016, when 56 biogas plants were in operation, 7 plants have ceased their operations by 2020, moreover, in 2020 at least 5 more biogas plants planned to close, mainly due to political instability [19].

In Europe, biogas is mainly produced by anaerobic digestion, followed by combustion in cogeneration plants or purified to biomethane purity level and fed into the natural gas network [23]. In 2014 there were 54 biogas plants operating in Latvia with a total capacity of 54.92 MW (3.1 PJ) and out of those 54 biogas plants, 44 used agricultural waste (82 % of biogas cogeneration plants operating in Latvia in 2014 were based on agricultural raw materials), 7 used municipal waste in landfills, but only 3 used domestic or industrial sewage and residues from food production (industrial waste), and all produced biogas burned in cogeneration plants [24].

This situation has arisen due to energy policy, moreover, support for subsidies has recently fallen not only in Latvia, but also throughout Europe, which explains the slowdown or even regression in the development of this sector. To understand the development so far and how it has come to this, it is necessary to look at the history of the industry.

3.2. Market driving trends and challenges in the biogas sector

Although the current biogas production potential is unused in many European Union countries, the growth of the biogas production is limited mainly because of the challenges in profitability, but also due to the uncertainty of political decisions [25]. Figure 1 shows the possible business options for biogas producers. As it is well known, traditional energy prices are low, but over time the role of heat production may increase if more and more electricity is obtained from non-combustion processes [25]. Meanwhile better short-term profitability is expected from the use of biomethane as a traffic fuel [25]. There could be room for new incentives through greenhouse gas emission trading scheme for farm-scale renewable energy production, for example, a market that pays for carbon sinks in agricultural land [25]. In addition, the production of recycled nutrients and biochemicals are considered as a future possibility [25].

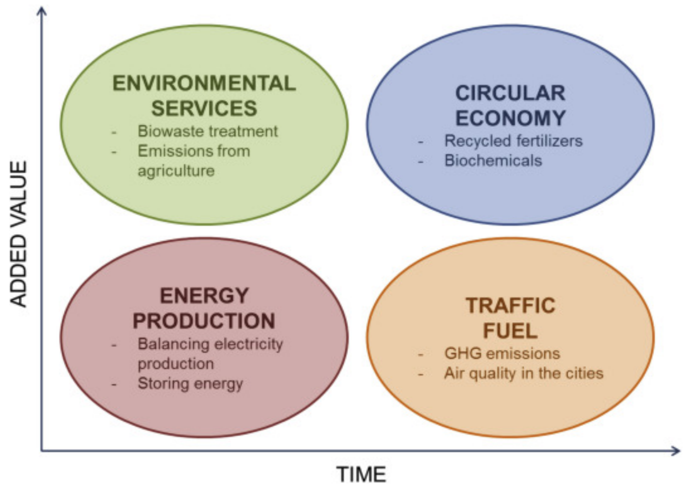

Fig. 1. Opportunities in biogas production – from energy to circular economy [25].

Biogas production in Latvia was economically supported by a mandatory procurement component (MPC), the elimination of which is now at the forefront of the promises of many politicians [26]. It is important to note that MPC's abolition and electricity's trading at stock exchange prices, as encouraged by Latvia's Minister of Economy Ralph Nemiro, would mean the closure or bankruptcy of many biogas plants [27]. The main mistake made in the MPC mechanism was to include natural gas cogeneration in this package from 1998, as a result of which in 2015 60 % of MPC payers' money went to imported natural gas producers, but only 40 % to renewables – biogas, hydro, biomass and wind energy producers, which is an indicator of the choice of a failed system [28].

In order to increase the efficiency of energy production, the so-called 'maizification' phenomenon began in the world, including in Latvia, when energy crops began to be grown on a very large scale for the production of biogas [18]. If in the production of biogas from cattle manure the yield of biogas is 35 m/t, then in the production of maize, the yield of biogas is 190 m^3/t [29]. Unfortunately, this means that fossil fuels were used in heavy machinery, but food products in anaerobic digestion processes to produce renewable energy [29].

All these circumstances led to another change in legislation, which provides for significantly stricter conditions for producers of renewable energy, including biogas. At present it is assumed that, starting from 2021, new mandatory procurement components come into force, where the total fee for MPC for all electricity users will consist of two parts, one which is fixed, but the other depends on consumed energy [30]. It is clear that it is also impossible to do without cogeneration plants, because then the price of electricity would rise and heat would be released into the air. At the same time, as financial support decreases, production conditions have increased:

- The regulations include additional requirements for biogas plants regarding the use of residual products, including manure, which means that biogas plants will have to reduce the use of food products, including maize, in biogas production from 2022:
  1) from 2022 to 2025, residual products / organic waste must make up at least 40 % of the total amount of raw materials consumed;
  2) from 2026 to 2029 at least 60 % of the total amount of raw materials consumed;
  3) from 2030 at least 80 % [31].
- The regulations include a link between the type of resources used in biogas production in a percentage of total amount of raw materials used and the price of electricity, which means that, if a merchant does not comply with the minimum requirements regarding the composition of raw materials to be used during the year, the regulations of the Cabinet of Ministers provide for the abolition of mandatory procurement rights, but for those who do, the coefficient for the price of produced electricity is applied accordingly [31], [32].
- The regulations define the principles of energy production and the use of useful heat energy, which means that the heat produced in cogeneration plants is used efficiently, including the fact that the total amount of useful heat does not include heat energy that is used for own consumption. If it is possible to produce electricity and useful heat at the same time, the actual total efficiency of energy production is 75 % or more [31], [33].

At the same time as biogas cogeneration plants have undergone changes, tightening restrictions, reducing financial support, politicians have issued a new announcement about the plans of the beginning of the biomethane era in Latvia [34]. Biomethane is planned to be introduced into the common natural gas network, while the consumption of the product is planned to be guaranteed by purchasing biomethane – powered school buses, agricultural tractors and fire trucks using financing from the new European recovery and resilience facility to recover from the Covid-19 crisis [34]. However, the production of biomethane requires treatment plants, which will be co-financed by European funds for the current period, but with the support of Cohesion policy, a gas connection and transmission network, filling infrastructure will be built [34].

The need to develop the biogas sector, as well as to transform it into biomethane, is indicated not only by the Paris Agreement and Green Deal, but also by several plans developed at the national level. Latvia's National Energy and Climate Plan (NECP) clearly indicates the aim to reduce energy dependency on third countries, eliminate energy poverty risks and promote public welfare in general to move to a sustainable, climate neutral and internationally competitive economy [35]. One of the main policy directions set out is the use of biogas resources and promotion of the production of biogas and biomethane to move towards fully decarbonized energy sector, including transport sector [35]. The plan includes several goals in the field of energy decarbonization, one of which is to promote the production and use of biogas and biomethane, achieving the use of biomethane in the amount of at least 3–5 % of the energy used in transport final consumption in 2030 [35]. Examining the relationship of the plan's context with the current Latvian and their policy planning documents on decarbonization and renewable energy issues, the link with at least 10 documents can be seen, for example:

- SDSL2030 (Latvia's sustainable development strategy for 2030), which emphasizes:
  - development of energy interconnections and decentralized energy production;
  - use of renewable energy sources and innovation, including use of biomass for electricity and heat production, use of biogas resources and biofuels;
  - supports environmentally friendly transport policy, innovation and modernization in agriculture and use of biomass [35], [36].
- LTESL2030 (Latvian energy long-term strategy 2030 – Competitive energy for society), which reports on the need to promote:
  - wider use of renewable energy sources in public transport;
  - the use of waste for energy production to increase the use of local energy resources at the same time solving the waste utilization;
  - the development of natural gas supply and storage infrastructure [35], [37].
- Rural Development Programme of Latvia 2014–2020, which motivates to:
  - improve fertilizer and pesticide management;
  - use of waste materials and development of bioeconomy;
  - reduce greenhouse gas and ammonia emissions from agriculture [35], [38].

There is another policy planning document – National Industrial Policy Guidelines (NIP), which sets out directions for actions for the next seven years, motivate Latvia's producers to develop competitive advantages related to technology and innovation, while working to make Latvia's industry more environmentally friendly, as an insufficient level of technological development is mentioned as one of the causes of low productivity in the country. While there are various obstacles to such a transformation, including the crisis caused by Covid-19, it is an opportunity to change habits and focus resources on future growth in sectors and industries, maintaining a strategic course and accelerating productivity-based economic restructuring. As Latvia has identified five knowledge-intensive areas, where both resources and expertise are available, two of which are smart energy and mobility, as well as the knowledge – intensive bioeconomy, these areas have been at the forefront of discussions in industrial policy, considering future transformative nature and higher added value activities. Thus, the introduction of the concept of Smart Specialization (RIS3) in research and innovation strategies implies the constant finding of competitive advantages, taking into account environmental protection and climate development.

These documents make clear the importance of biogas and biomethane for the future, which is also part of the bioeconomy system, the main aim of which is to find new ways to produce and consume resources away from a linear economy based on the extensive use of fossil fuels and minerals [39]. In addition, the production of biogas or biomethane directly produces not only green energy, but also digestate as a by-product containing a significant amount of nutrients, which is suitable for fertilization [40], which is one of the biggest benefits of biogas production, because fertilizing fields with digestate can indirectly reduce greenhouse gas emissions, for example, a digestate, derived from 1 ha of corn green matter provides full potassium for the field fertilization and saves 31 % phosphorus and 44–45 % nitrogen [41]. Thus, it has ability to reduce nitrogen fertilizer amount, in addition, the precise use of the necessary fertilizers also reduces nitrous oxide emissions by reducing nitrogen levels [42].

This increases the uptake of carbon dioxide through higher productivity and the introduction of biomass into the soil [42].

Despite the policy goals, there are a number of concerns about putting the biomethane idea into practice in Latvia and one of the biggest concerns is investments required in the compression equipment, so the biomethane could be transported to another company or place for use in vehicles. Biomethane transportation by trucks works as an alternative, if the biogas plants are not close to the natural gas network [43], [44]. However the gas has to be compressed to 200 bars to be used as a fuel, and 200–250 bars to be transported by trucks [43]. As Latvia plans to use biomethane in heavy vehicles, it is also necessary to dilute it, because then the energy density is much higher and therefore longer distances can be reached with the same fuel storage capacity [43].

4. Sustainability SWOT Analysis

The sustainability SWOT analysis, where strengths, weaknesses, opportunities, and threats are analysed, is a new twist on the familiar SWOT, where much more can be incorporated than environmental issues [45]. It is a very simple method to be effectively used not only for companies and resource planning, but also for strategy prioritization at industrial and policy level [45], [46]. The analysis is designed to drive collaboration on environmental challenges, possible risks and opportunities, which otherwise may go unnoticed.

Based on the obtained literature review, a table was created accordingly, in which the strengths, weaknesses, opportunities and threats were defined [47].

TABLE 1. COMPILED ASPECTS FOR sSWOT ANALYSIS

Strengths	Weaknesses
Great deal of experience and knowledge has been accumulated; Developed biogas sector, major investments have been made in existing equipment; Extensive and highly developed agricultural sector.	Potential of biogas is not fully exploited; Negative public opinion and perception of biogas due to previous experience with the Mandatory Procurement component; Major investments are needed in biomethane treatment and compression equipment; Uneven distribution of stations in the regions of Latvia; Impact and sustainability assessment of each biogas plant is needed.
Opportunities	**Threats**
Reduce emissions from the energy sector, including transport sector; Reduce agricultural sector emissions and pollution; Make full use of by-products; Latvia can meet all climate goals; To promote the involvement and interest of regions and companies in cooperating in the development of a single, effective system.	In the future, the bioeconomy will increasingly develop, taking over part of the stock; Reduction of financial support for biogas production; Strengthening biogas production criteria; Human factor in operational control mechanisms.

The summarized aspects show that the sector is already facing various difficulties and future threats due to the forthcoming change, but it has no less strengths and opportunities. Looking at the strengths, it is clear that biogas production is especially suitable for Latvia due to its developed agriculture. The biogas sector in Latvia is also developed, large investments have already been made in it both on part of companies – producers and on part of the citizens of the country, purchasing renewable energy produced from biogas in cogeneration plants for higher price. This is a testament to the extensive knowledge and experience already gained. At the same time, the sector has acquired a bad reputation and attitude among the citizens due to the conditions of the disorderly mandatory procurement component, causing great resistance and suspicion among energy consumers, who are no longer willing to support the sector financially. Since the potential of biogas has not been fully exploited, transition from cogeneration to biomethane production will again require significant investments. Considering the fact that there are many, but relatively small power stations in Latvia, which are unevenly distributed throughout the country, the question remains, whether it is planned to build treatment and compression equipment separately for each small biogas plant. It is not yet clear, how to do this more effectively, as no impact and sustainability assessment has been carried out for each biogas plant to understand, how smart it would be for stations to promote the change.

Whereas the transition to biomethane will require new knowledge of the operation of the stations, one of the risks is the possible errors made by the human factor, which would delay and hinder proper production and resource management. It must also be kept in mind that the bioeconomy is likely to develop rapidly in the future, which could possibly take over some of the raw materials from which higher value-added products would be produced. However, given that legislation has been adopted to strengthen biogas production criteria while reducing financial support for electricity produced in cogeneration plants from biogas, switching to biomethane production, seems an opportunity to save the viability of the biogas sector in Latvia and help to meet the climate goals by reducing emissions in energy, transport and agriculture sector and pollution, making full use of by-products. While unreasoned and short-sighted management could be the next threat to the industry, smart management could at the same time encourage the involvement and interest of regions and companies in working together to create a coherent framework for a well-designed strategy for smart investment, financial autonomy and independence, which leads to an affordable product.

5. CONCLUSIONS

This research reflects current situation and where the current policy is driving the biogas sector in Latvia. It is clear that biogas sector has a future and development potential in Latvia if it is properly managed. So far, despite the errors in the distribution of subsidies, entrepreneurs have gained a great deal of knowledge in this sector. One of the biggest advantages of the Latvian biogas sector is highly developed agriculture. The sector as a whole is very well developed and huge investments have been made, but currently the sector is unsustainably managed. It is highly financially dependent on state aid. The transition of biogas from cogeneration to biomethane, as a result of current decisions, seems to be a way to save the viability and sustainability of the sector. It could reduce not only emissions from the agricultural sector, but also emissions from energy and transport sector to meet the climate goals. At the same time, the sector faces the following challenges:

- reaching maximally efficient and smart system that involves biogas producers and regions in planning investments;
- being as financially independent as possible in the future;
- changing the negative public opinion and perception;
- bioeconomy development, which may take over part of the stock;
- achieving maximum resource efficiency;
- playing its full role on the way to climate neutrality and reducing agricultural, transport and energy sector greenhouse gas emissions;

– critical assessment of the sustainability and resource availability, the possible way of selling the product for each biogas plant.

Aware of the challenges identified in this article, policy makers and entrepreneurs will be able to plan more strategically for the next steps in the development of the biogas sector, with a stronger focus on sustainability aspects.

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Ranking of Bioresources for Biogas Production

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

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

1. INTRODUCTION

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

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

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

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

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

TABLE 1. YIELD OF VARIOUS RAW MATERIALS [18]

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

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

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

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

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

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

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

2. METHODOLOGY

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3. RESULTS

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

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

TABLE 5. CALCULATION OF ECONOMIC JUSTIFICATION FOR EACH SUBSTRATE

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

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

TABLE 6. MULTI-CRITERIA ANALYSIS VALUES

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

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

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

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

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

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

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

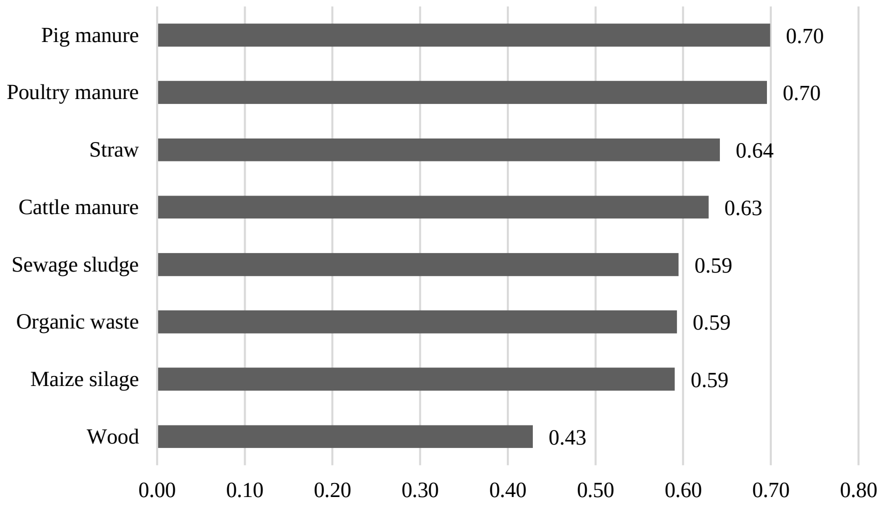

Fig. 1. Relative closeness to the ideal solution with TOPSIS method.

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

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

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

4. CONCLUSIONS

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

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

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

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

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

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Sustainable biogas application in energy sector

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Although European Union has set a target for all Member States that by 2050 the share of renewable energy sources has to achieve at least 55% in gross final energy consumption, it is necessary to assess the conditions under which such a policy is sustainable. The use of biogas in energy sector is one of the possible solutions. Transport sector consumed 30.1 % of the energy resources (2018) in Latvia and given that it is the largest and the agricultural sector is the second largest sector responsible for GHG emissions in Latvia, this study uses Latvian data to examine the optimal solutions for increasing the share of renewable energy in the transport sector, balancing it with a sustainable strategy for the agricultural sector. This study focuses on the impacts and effectivity of biogas application in autotransport. The study examined the case of biogas used in cogeneration plant and electricity produced in cogeneration for autotransport versus the conversion of biogas into biomethane for the use of autotransport. The results obtained not only suggest the most efficient solutions for the use of biogas in the future, but also indicate environmental, economic and social aspects.

Keywords—multicriteria analysis, impact assessment, investments, renewable energy, autotransport

I. INTRODUCTION

Production of biogas using bioresources of agricultural origin plays an important role in Europe's energy transition to sustainability [1][2][3] to achieve climate-neutral economy by 2050 and to keep global temperature increase below 2 °C above the pre-industrial level [1][4]. Biogas is the most challenging renewable fuel in terms of potential assessment [5] due to the possibilities to use it for different purposes – transportation fuel, heat and electricity generation [6]. If biogas is utilized in a technologically efficient way and sector, it can not only make an economic contribution, but also reduce emissions [7], however inefficient use can affect not only the economy, but also the environment and food competition [8][9].

Biogas is mainly associated with two sectors: agriculture and energy. Taking into account that the energy sector is responsible for 64.0% of the total GHG emissions in Latvia, of which the transport sector is responsible for 44.2%, while the agricultural sector is responsible for 23.6% of the total Latvian GHG [9], as a result of efficient use, biogas can have a positive effect on reducing emissions from both sectors [10].

Although there are various forms of support for biogas producers in Europe and elsewhere in the world [11][12], the legislation in Latvia is so unstable and various in this area that entrepreneurs are afraid to invest in biogas or treatment plants, therefore, despite the fact that the number of stations should increase [13], it decreases every year [14]. Given that, in theory, a biogas plant must be able to operate economically independently, even without public subsidies, in parallel with its main task of reducing emissions, the main challenge is to provide practically valuable material with technological information on how to achieve it with maximum efficiency.

The aim of the study is to find the sustainable application for the use of biogas in energy sector, taking into account economic feasibility, technological and environmental aspects. The conversion of biogas to biomethane and its use as vehicle fuel has greater potential and greater justification than biogas combustion [15] in CHP unit. Since 2016, Latvia has adopted a law that it is possible to inject biomethane into the natural gas network, but the regulation on methane concentration, which must be more than 90%, as well as other quality characteristics, is very difficult to achieve [16], in turn, the technologies require investments, as well as infrastructure or tax incentives, but the state does not support it yet, but provides for a tax on biomethane [17].

The focus in this research is on agricultural biogas, which can be used for 2 purposes in energy sector: (a) combusted in CHP, as well as electricity used for autotransport; (b) purified to biomethane used for autotransport (see Figure 1).

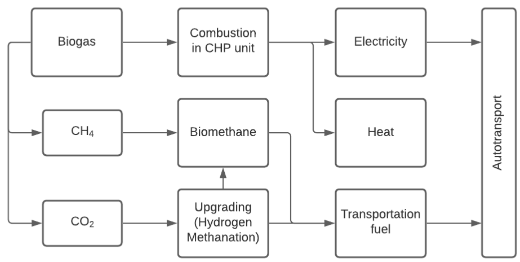

Fig. 1 Biogas application

The methodology is demonstrated on Latvia as a case study.

II. METHODOLOGY

To achieve the goal of this research – evaluate the sustainability of biogas application in energy sector, a multicriteria analysis has been used. During the fist step of the research, data collection and analysis, including systemic review od scientific literature, initial data and regulations were done. Based of results of the fist step of study, indicators (technical, environmental, and economic) used for multicriteria decision making process, were identified, and selected. The TOPSIS method used in this work to make a decision was "The classical

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TOPSIS method for a single decision maker". During the next step values of indicators were set and after the normalization and weighting of indicators, rating, and evaluation of biogas application scenarios in energy sector was conducted. Weights were determined by energy experts from Institute of Energy Systems and Environment. The methodological algorithm of the research is shown in Figure 2.

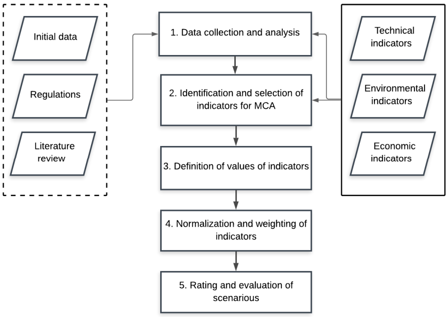

Fig. 2. Concept of the methodology

The methodological algorithm was applied on case study of Latvia, but this methodology can be used for the evaluation of biogas application in another countries as well, adapting data and regulation of a country ect.

III. RESULTS

Although biogas production is particularly suitable for Latvia, because agriculture in Latvia accounts for 24,6 % of total GHGs, ranking as the 2^{nd} largest GHG emitting sector, since 2016 [9], when 56 biogas plants were in operation, 7 plants have ceased their operations by 2020, moreover, in 2020 at least 5-6 more biogas plants are planned to stop operating. At the same time transport sector is the biggest GHG emitting sector in Latvia and although EU member states must ensure 10% of renewable energy consumption in transport sector by 2020, when in 2018 its share was only 4.7%, biogas is not used in the transport sector at all [18]. All of the 11 million m^3 of biogas produced in 2018 is being combusted in cogeneration plants (installed capacity 61.22 MW with 80% workload) due to its high efficiency (90% in total – 50% thermal and 40% electrical) [19] and used in agriculture or similar sectors as heat and electricity [18]. Although there is great potential in biogas purifying to biomethane, it does not reach the maximum efficiency, since the raw gas contains approximately 65% CH_4 and 35% CO_2 of the volume, so acquisition of biomethane is measurable on average 63% [20], therefore upgrading of biomethane, for example by hydrogen methanation, should be done, which allows to increase CH_4 output of the biogas system by 70% [21].

One of the main policy directions set out in the current policy planning document to achieve the goal set in a particular policy planning document is the use of biogas resources and promotion of the production of biogas and biomethane and the use of biomethane and it is implemented in all target farms to produce biogas and purify to biomethane, which is also determined with a relevant legal acts to ensure the installation of biogas treatment plants within the EU structural funds or other sources of financing in the period after 2021 [3][17].

The transition from fossil fuels to biomethane could be one of the main ways of meeting the transport sector's goals. It could not only economically benefit farmers, who would save on fertilizer costs, but also reduce GHG emissions in manufacturing industry by not making these mineral fertilizers and using the digestate instead [22].

Given that the largest consumption sector in final energy consumption is transport, as well as the fact that the transport sector is the largest source of GHG emissions, to set the lowest possible excise tax rate for biomethane and biofuels from 2022, evaluating the possibility to differentiate the reduced rates for first generation biogas [17].

During the research, taking into account Latvian conditions, two scenarios found to be sustainable for biogas application in energy sector (see Table 1).

TABLE 1 DESIGNATION OF BIOGAS APPLICATION SCENARIOS

Designation	Biogas application practice
Scenario 1	Combustion in CHP unit, produced electricity used in transport sector
Scenario 2	Production of biomethane and used in transport sector

For the assessment of competing scenarios, indicators for the technical, environmental, and economic dimensions were developed. Mentioned indicators were established after literature review and gathering the opinion of experts in this area. Five indicators were used to analyse biogas application options in energy sector (see Table 2).

TABLE 2 INDICATORS USED FOR THE ASSESSMENT OF BIOGAS APPLICATION SCENARIOS

Dimension	Indicator	Unit	Preferable outcome
Technical	Efficiency of the whole system	%	Max
	Efficiency gains for the transport sector	%	Max
	Energy produced for transport sector	MWh	Max
Environmental	Reduced GHG emissions	$ktCO2_{eq}$	Max
Economic	Costs	Euro/MW	Min

These five criteria from three dimensions were used for the assessment of analysed scenarios. Criteria weights were determined by experts in the field. Values for indicators were obtained both from the literature and Latvian Biogas Association.

The inventory submitted in 2018 indicates that in 2016 the emissions of the energy sector were 7239.16 kt CO_2 eq, thus, if

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the transport sector is responsible for 44.2% of emissions from the energy sector [18], it equals to 3199.71 kt CO_2 eq.

As the transport sector also include emissions from air traffic, emissions from diesel fuel were also considered separately in this work, and in 2016 a total of 753000 t was used in transport sector, but 693000 t or 832932692 l was used in autotransport [23]. Assuming that 1 l of diesel equals 1m^3 of biomethane, which is 10 kWh in terms of energy [24], it is possible to calculate the potential impact on the environment if biomethane were produced from all currently produced biogas, as well as compare the impact if all electricity already produced in cogeneration plants from biogas were used in electric cars.

By finding out the lowest combustion heat of diesel fuel (0.043 TJ/t) [25], it is possible to obtain process energy for field treatment [26]. Knowing the energy consumed in the process in field cultivation as well as using the emission factors of the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines:

CO_2 emission factor is 74.74849 t/TJ = 0.269 t/MWh;

CH_4 emission factor is 0.00415 t/TJ = 0.015 kgCO_2/MWh;

N_2O emission factor is 0.0286 t/TJ = 0.103 kgCO_2/MWh;

it is possible to obtain the result in terms of tons of emissions from the use of fuel [17].

Taking into account the total installed electrical capacity of all stations in 2018, which, according to the Latvian Biogas Association board member, was 61.22 MW, while average workload was 80%, and Biogas Association Member's given data of produced electricity, using biogas, in cogeneration plants produced 347.94 GWh of electricity, which could be used for electric cars as a climate neutral or negative fuel in transport sector.

As the mandatory target for renewable energy in transport by 2030 is 14% [17], with the use of already produced biogas in cogeneration plants, while the use of electricity from cogeneration in transport, it would already provide 4.18% share of renewable energy in road transport sector's diesel fuel use and 4.13% reduction of whole transport sector emissions according to 2016 transport data.

According to the Central Statistical Bureau, 11 million m^3 of biogas was produced. If all this biogas were used for methane production, 6.93 million m^3 of biomethane would be produced with 63% efficiency, while an additional methane would be produced during hydrogen methanation process from the rest of the biogas, which contains of 35% carbon dioxide, and could be used in the transport sector. Biological hydrogen methanation could not only increase the biomethane yield, but also lower the costs for biogas upgrading to natural gas quality [27]. Efficiency of the process in a cogeneration plant right after the methanation is 30-45% (37.5% on average) [27], which means that if 4.07 million m^3 carbon dioxide is produced, then with biological hydrogen methanation digesters it is possible to maintain 1.83 million m^3 of methane. Knowing that 1 l of diesel equals 1m^3 of biomethane, which is 10 kWh in terms of energy [28], the potential impact on the environment would be 1.83 million l of saved diesel fuel, which means 18.3 GWh.

Values for economic indicators were obtained from literature and represent capital costs for biogas production and cogeneration in CHP unit and biogas production and upgrading to biomethane.

Multicriteria analysis method TOPSIS were used for the determination of the best scenario for biogas application in energy transport. Normalized and weighted decision-making matrix showed in Table 3.

TABLE 3 NORMALIZED AND WEIGHTED DECISION-MAKING MATRIX

Indicators	**Technical indicators**			**Envir. indicator**	**Econ. indicator**
	Efficiency of the whole system	Efficiency gains for the transport sector	Energy produced for transport sector	Reduced GHG emissions	Costs, Euro/MW
Scenario 1	0.076	0.093	0.098	0.291	0.260
Scenario 2	0.065	0.177	0.021	0.073	0.150

The results of multicriteria analysis are showed in Figure 3.

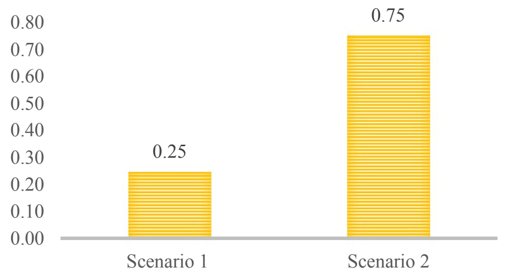

Fig. 3 Results of multicriteria analysis

The results obtained from evaluation of scenarios using TOPSIS showed that biogas upgrading and use of biomethane as transport fuel is the optimal solution for Latvia and has a highest Relative Closeness to the Ideal Solution (Ci).

IV. CONCLUSIONS

During the research, the sustainable application of biogas for energy sector was evaluated. The study examined the case of biogas used in cogeneration plant and electricity produced in cogeneration for autotransport versus the conversion of biogas into biomethane for the use of autotransport.

Latvia was used us a case study in this work. This study focuses on the impacts and effectivity of biogas application in autotransport. The research shed light on sustainability aspects of biogas production and use in future and on how the renewable energy applications can move forward in Latvia.

TOPSIS method was used to evaluate two scenarios: 1) biogas production and cogeneration in CHP unit and use of

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electricity produced in CHP unit for the autotransport; and 2) biogas upgrading to biomethane and use of it for the autotransport.

The results obtained show that biogas application for the production of biomethane is the best and more sustainable solution for Latvia. The used methodology can be used by decision makers, government, scientific society for the evaluation and analysis of biogas application options in Latvia or other country of the European Union.

Future studies should be done on sustainability assessment of biogas application in energy sector, including social dimension and complementing existing indicators.

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Carbon balance of biogas production from maize in Latvian conditions

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

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

INTRODUCTION

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

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

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

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

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

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

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

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

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

METHODOLOGY

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

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

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

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

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

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

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

$$N_2O = N_2O - N \cdot 44/28 \quad (2)$$

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

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

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

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

$$R_{AG} = \frac{AGDM \cdot 1{,}000}{Crop} \quad (4)$$

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

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

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

$$\text{Crop} = \text{Yield Fresh} \cdot \text{DRY}, \quad (6)$$

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

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

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

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

RESULTS AND DISCUSSIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

CONCLUSIONS

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

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

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

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

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Development and Assessment of Carbon Farming Solutions

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***Abstract* – In the light of the Green Deal and its 'Farm to Fork' and 'Biodiversity' strategies, the EU aims to find new ways to decrease GHG emissions through the EU Carbon Farming initiative stating that farming practices that remove CO_2 from the atmosphere should be rewarded in line with the development of new EU business models. The Carbon farming initiative is a new approach and concludes that carbon farming can significantly contribute to climate change mitigation. As European Commission acknowledges that carbon farming is in its infancy and there is a lot to be addressed, in the years towards 2030, result-based carbon farming plots and schemes should be settled by the Member States and local governments; therefore, the existing solutions for reducing emissions through improved farming practices should be defined for each region. The research identifies carbon farming solutions in the agriculture sector – minimal/zero tillage, carbon sequestration in soils, biogas and biomethane production, perennial plant growing, and agroforestry and described.**

***Keywords* – Agriculture emission mitigation; biodiversity; biogas production; biomethane; carbon farming methods; CO_2 sequestration; minimal tillage; perennial plants; soils; solutions; zero tillage**

1. INTRODUCTION

Carbon is the atom of life and not only by carbon-based fossil fuels our vehicles, homes, and factories are powered, but it is also used in chemicals, plastics, advanced materials, steel of our cities involves processing carbon, half of the food is carbon, and it is even in human DNA [1]. However, the concentration of carbon dioxide in the atmosphere has increased significantly, mainly due to the combustion of fossil fuels in industrial processes [2] and the activities of various other sectors [3], [4].

Carbon dioxide (CO_2) is a renewable [5], inexpensive [6], safe gas with a balanced geographic distribution [7], mainly known as a greenhouse gas that significantly contributes to global warming [8]. Although CO_2 is a relatively low energy and inert molecule, its involvement consumes much energy and not enough developed processes [7]. Therefore, it is essential to identify the directions with the most significant potential for the sustainable and efficient use of CO_2 in production rather than negatively impacting the economy and the environment.

Although negatively impacting utilisation will not significantly reduce global warming [9], more and more research has come up with different solutions for using CO_2 in various industries' production processes, replacing fossil fuels, for example, in chemistry [10],

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transport [11], food production and processing [12], in the production of various daily necessities [13], [14], thereby promoting sustainable development and reducing greenhouse gas emissions in the atmosphere.

In the light of the Green Deal and its 'Farm to Fork' and 'Biodiversity' strategies, the EU aims to find new ways to decrease GHG emissions through the EU Carbon Farming initiative stating that farming practices that remove CO_2 from the atmosphere should be rewarded in line with the development of new EU business models [15].

The Carbon farming initiative is a new approach for Europe. Its main objective is to create direct incentives to encourage the agriculture and forestry sectors to deliver on climate and biodiversity action and contribute to the European Green Deal. The initiative [15] concludes that carbon farming can significantly contribute to climate change mitigation, and European Commission acknowledges that carbon farming is in its infancy. There is a lot to be addressed. The European Commission highlights that carbon farming can be promoted via EU and national policies and private initiatives. In the years towards 2030, result-based carbon farming pilots and, eventually, schemes should be settled by Member States and local governments. Therefore, solutions for reducing emissions through improved farming practices should be defined for each region [16].

Climate change is included as one of the specific objectives of the current common agricultural policy, promoting the implementation of technical measures for both mitigation and adaptation at the farm level. The agriculture sector keeps an essential role in Latvia's economy. The most significant part of the population lives in rural areas, approximately 84 % of the total area. The agricultural sector is responsible for 28.5 % of Latvia's total non-EU ETS GHG emissions in Latvia. Latvia reduced GHG emissions from agriculture between 1990 and 2018 by 53 %; however, in the latest years and projections show a rising trend most significant part of emissions is related to agricultural soils (59.3 %) and enteric fermentation 32.6 % (mainly dairy and beef cattle). The GHG emission trend of recent years shows a gradual and steady increase in GHG emissions; for example, between 2005 and 2018 + 12.5 %, and during the period 2013–2018, emissions increased by 2.12 %. According to Latvia's National Energy and Climate Plan 2021–2030, total GHG emissions in the agricultural sector are expected to increase from 2020 to 2030, mainly in the enteric fermentation and agricultural soil categories. To achieve determined targets for Latvia's non-EU ETS sector in 2030 and be on track to reach climate neutrality in 2050, the agriculture sector must contribute to GHG emission mitigation. Improved food security and climate-smart activities will be necessary for the agriculture sector to achieve GHG emission reduction.

The European Green Deal is planned to improve people's well-being and make Europe climate-neutral, including decreasing emissions while creating jobs [17]. To move on with these ambitions, EC proposes to revise relevant climate policies, for example, targets to reduce emissions in sectors outside the EU ETS. Reaching these ambitions will require action by all sectors of the economy, including agriculture; nevertheless, it is not easily achieved. One of the main challenges facing the agricultural industry is to provide food for the increasing population while reducing its influence on the climate and environment.

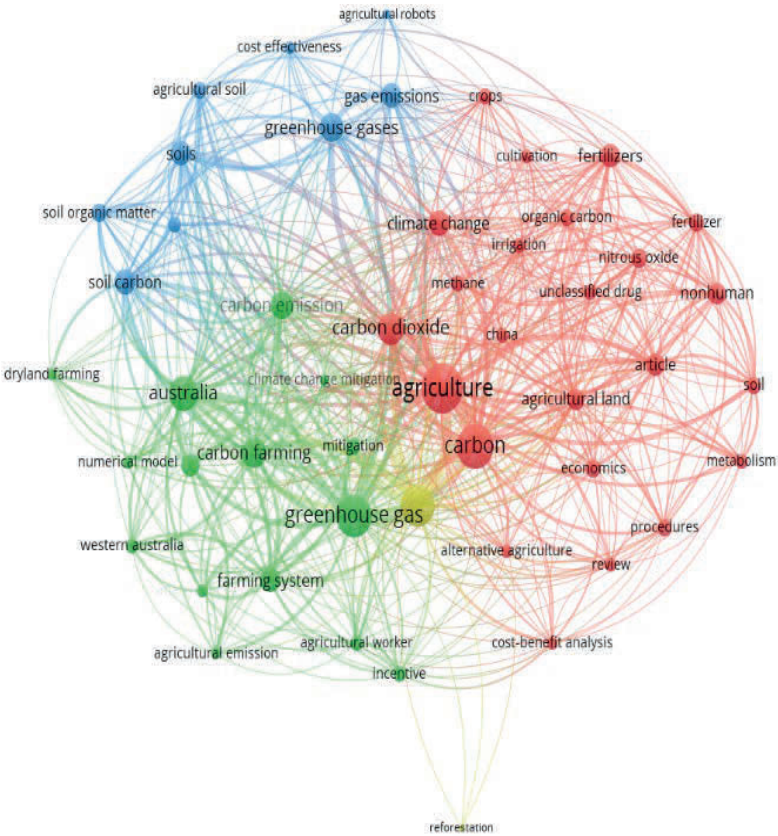
Carbon farming mainly aims to trap carbon in soil and vegetation because of the co-benefits of fertility and productivity boost [18].

As an increasing number of private carbon initiatives have emerged, where land managers sell carbon credits on voluntary carbon markets, it is the right moment to improve high-quality supply in the EU [1]. The best practice would be to prevent a large-scale lift-off and ensure adequate reward for the carbon credits, but on the supply side, carbon farming credits should become an additional 'product' for sale [1]. It would be a new source of income for land managers [1].

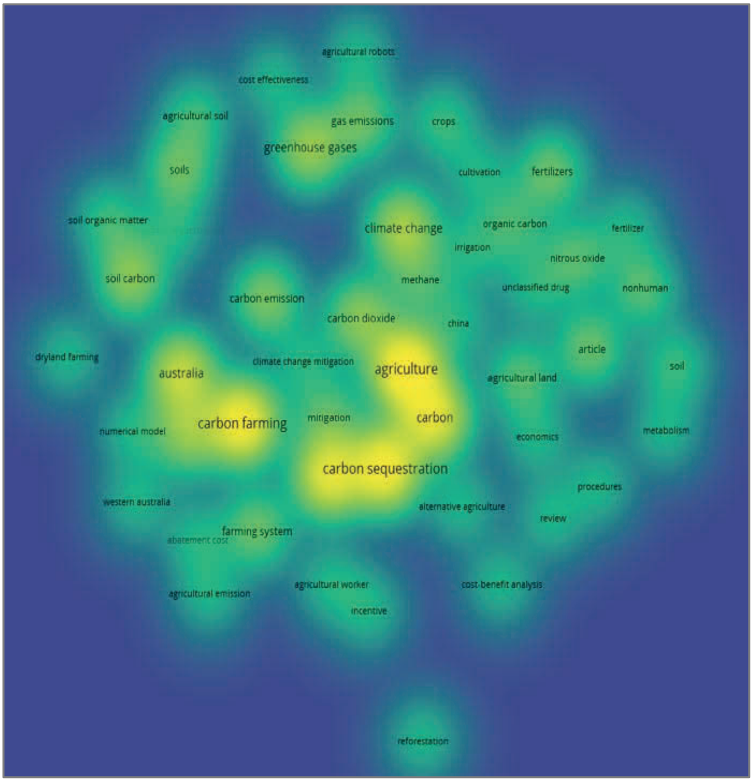
Carbon farming solutions for Latvian conditions will be identified in the research, and their importance in reducing GHG emissions will be determined and evaluated.

2. LITERATURE ANALYSIS

To evaluate the current state of carbon farming and how it is connected to other topicalities and the leading technologies used to achieve it, a bibliometric analysis using *VOSviewer*© was conducted. Scientific publications on the Scopus database with the keywords 'carbon farming' and 'agriculture' were searched. Fifty-three publications were found with these two terms with 50 keywords when a co-occurrence constraint of at least five co-occurrences is considered. This means the bibliometric network presented in Fig. 1(a) displays those keywords that appear at least five times within the publications. The links displayed between items represent a co-occurrence in a source, each connection with a strength score; the higher the value, the stronger the association. Such a strength score represents the number of publications in which both keywords appear together (co-occurrence) [19].



(a)



(b)

Fig. 1. (a) Network visualization; (b) Density visualization.

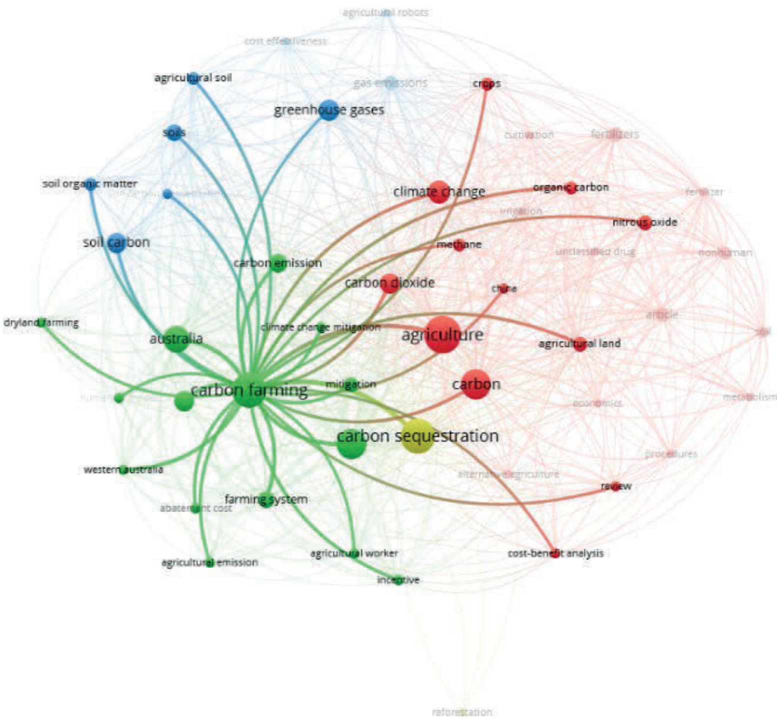
Fig. 1(b) shows the occurrences density visualization of each keyword for the network, with ‘carbon sequestration’, ‘carbon farming’, agriculture’, ‘carbon’, and ‘Australia’ being the most common items. When the ‘carbon farming’ keyword is analysed within the network (see Fig. 2(a), the main topics connected to it are shown, some of them of importance to this work as some techniques are observed. The yellow cluster for instance (see Fig. 2(b)), displays two current technologies, carbon sequestration with occurrences in 18 out of 50 publications and 46 links, and reforestation with only three occurrences and four links.

Another interesting analysis from the network is the fact that the link between ‘carbon farming’ and ‘agriculture’ does not have considerable strength in the network with a score of 5, with the stronger links to exists among ‘carbon’, ‘agriculture’, and ‘carbon sequestration’ showing scores between 9 and 13. When it comes to deep research on carbon farming techniques, the lack of related keywords in this network is noticeable, with most studies focusing on types of crops, economic evaluations, and GHG emissions.

To achieve the goal of this research – to identify carbon farming solutions for Latvian conditions and determine their importance in reducing GHG emissions, a literature review has been conducted, mainly analysing reports, legislation, scientific articles that were identified as a relevant material to provide an understanding of some of the possible solutions for carbon farming in the Latvian agriculture sector. The search was performed mainly using Google, ScienceDirect, Web of Science, and Google Scholar. The review was done based on the agricultural situation of Latvia, but it can be used for other countries too.

In 2018, only 1 % of the approximately one billion tons of biogenic (45 %) and fossil (54 %) carbon was recycled [1]. Fossil carbon should be replaced by carbon derived from waste, the atmosphere, and sustainably harvested biomass, to produce such products as plastics, synthetic fuels, rubber, and various value-added materials and chemicals [1]. Biogenic carbon will play an essential role in construction, providing substitutes for conventional building materials with alternative materials that can store carbon long [1].

It can already be seen that by 2030, the Innovation Fund will provide financial support of 25 billion EUR (at a carbon price of 50 EUR/t CO_2) for companies to invest in clean technologies, CCU, CCS, and carbon sequestration [1]. To achieve climate neutrality, by 2050, each CO_2 eq. ton emitted into the atmosphere will have to be balanced by a ton of CO_2 captured in the atmosphere. It means significantly reducing emissions and increasing carbon sequestration as an input to the production of various products.



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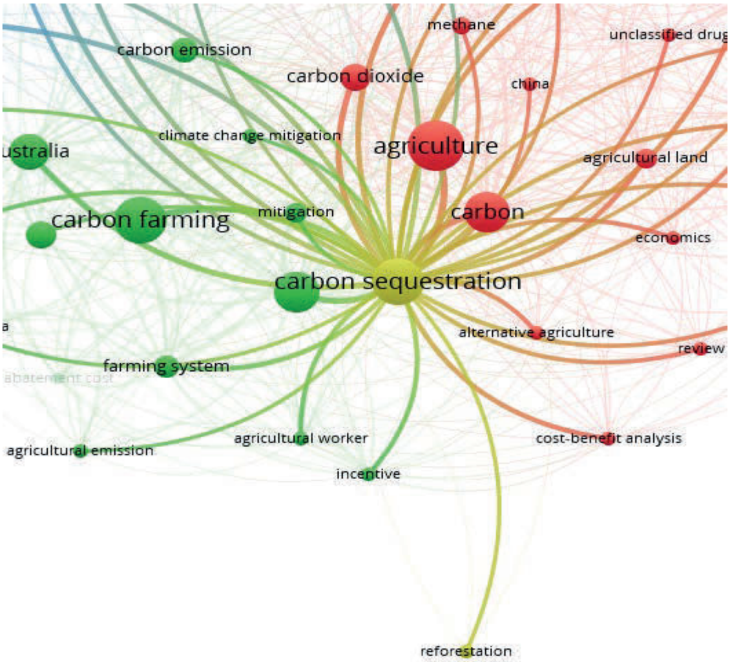

(b)

Fig. 2. Carbon farming links and relationships.

2.1. Zero/Minimal tillage

In 2018, 59.3 % of all emissions in the Latvian agricultural sector were caused by tillage, and 57.2 % of the arable land and these lands are occupied by cereals, which makes it a priority for the necessary change [20]. It is important to note that the treatment of agricultural soils includes emissions from the use of tractors and the use of fertilizers and post-harvest residues, which are later incorporated into the soil [21], [22].

The Strategic Plan of Latvia's Common Agricultural Policy also attaches great importance to reducing GHG emissions from agricultural land management by promoting more sustainable practices. The main aim of the activity is to encourage the use of sustainable agricultural production methods in the management of agricultural lands. It includes precise, well-thought-out fertilizers and plant protection, the cultivation of a single crop in a defined area for a maximum of 3 consecutive years, and the provision of green cover during part of the perennial planting area the growth season.

Reducing emissions from post-harvest residues is unfortunately not possible, as although, in theory, these residues could be collected and used in biogas or biofuel production with a 28 % reduction of GHG emissions, this is by no means acceptable, as it would have a negative impact not only on soil quality but also on the environment as a whole [23]. Even if crop residues are harvested below 25 %, it can lead to segment losses during the rain. Therefore studies show that only a minimal proportion can be removed, but it would be neither economically justified nor rational [24]. It means that the emphasis must be on reducing emissions from fuels and fertilizers; in addition, studies have shown that fuels and fertilizers are responsible for most of the GHG emissions from the agricultural tillage [25], [26].

Although high hopes are for electric tractor development, it is essential to look for solutions today. One solution is a sustainable agriculture technology based on reduced tillage to preserve soil structure and organic matter – minimal or even zero tillage [27].

In Europe, minimum and zero tillage methods have been used for decades. Still, in Latvia, 91.2 % of soils are cultivated with conventional tillage, while the energy consumption of this technology is 26 % higher than at minimal tillage and 41 % higher than at zero tillage [28].

To achieve sustainable agriculture and save emissions, various activities must be carried out in several stages, one stage lasting at least two years and consisting of 4 steps:

1. Minimum treatment methods are introduced (ploughing is stopped);
2. Under the influence of organic matter, the soil is improved due to the decomposition of crop residues, but the number of pests increases, which must be controlled with the help of chemicals;
3. The common system is stabilized, and the diversification of cultivation systems is introduced with intercultural cultivation;
4. The new farming system strikes a balance that can improve productivity compared to conventional farming and reduce the need for fertilizers and plant protection products [27].

Although the introduction of such a system takes an average of 6 years and yields during those six years can be significantly reduced, GHG emissions would be saved considerably and eliminated by reducing the amount of diesel and labour used, as well as fertilizers and plant protection products, in addition, the potential income from carbon farming would make such shift more motivating for farmers [29], [30]. Faster results can be achieved with the most modern seed drills without ploughing technology, where the seeds are pressed directly into the ground with a particular disc. Because direct sowing does not require many processes, the cost of working hours, fuel, spare parts, and repairs, and operating costs are reduced when productivity is not reduced [30], [31]. When choosing this technology, it is most important to pay attention to the sown interculture because it is the intercropping that provides the necessary minerals to the soil and creates micro-reclamation with plant roofs, preventing the soil from drying out or leaching fertilizer [31]. Choosing the right intercultures makes it possible to control weeds and various diseases, resulting in a significant reduction in the need for plant protection products [31].

2.2. Biogas production

The importance of renewable energy development for the decarbonization of the energy sector is already recognized [32], and biogas production is particularly suitable for Latvia because agriculture in Latvia accounts for 24.6 % of total GHGs, ranking as the 2^{nd} largest GHG emitting sector [33]. Biogas is produced by anaerobic fermentation – it is an environmental technology [34] that has been used for a very long time and is entirely developed [35]. Biogas produced by anaerobic digestion prevent greenhouse gas emissions and produce renewable energy from waste and provide for the production of processed fertilizers, improving nutrient self-sufficiency in the agricultural sector [36].

After biogas extraction, it has mainly two options for further use – its combustion to provide heat and electricity at cogeneration plants or to upgrade to biomethane to use it as a road fuel [37]–[39]. Both in Europe and Latvia, the industrial use of biogas is based on power generation through combined heat and power units [40], [41].

The productivity of a biogas plant depends on different aspects, like the type of biomass [42], digestion [43], availability of biomass, impurities that may harm microorganisms [44], and lignin content [45]. Almost any organic material can be used for biomass production, for example, paper, grass, animal waste, domestic or manufacturing sewage, food waste, agricultural products, etc. [46]. However, some substrates can be problematic with their various applications; for example, the use of agricultural crops to produce biogas represents an increase in competition for land use to make animal or human food [47]. Unlike the competition for land use in the agricultural crop sector, manure needs to be treated to avoid GHG emissions in the air. Studies indicate that the addition of manure is necessary to ensure a sufficient level of micronutrients for the digestion process [47].

Biomass pre-treatment is essential to evaluate and purify it to a state where the fermentation process is not disturbed. The inorganic additions and biomass, which contain too much lignin and are inappropriate, are removed [48]. In addition, in anaerobic digestion, it is essential to use co-digestion, which increases the productivity of produced biogas from 25 to 400 % over mono-digestion [49],[50]. To conclude, manure is the most suitable material for the biogas production [32], but it has a meagre carbon ratio. It is essential to mix it with other substrates; for example, in Latvian conditions, the best solution would be manure and straws combined [51]. It is important to note that fields with untreated manure may only be treated after at least eight months of holding because, during that period, pathogenic microorganisms die [52]. It is one more reason why it is so essential to develop biogas production and reduce not only emissions but also reduce environmental pollution risks – it is one of the most critical co-benefits of the carbon farming [53].

2.3. Biomethane

Decarbonization and gasification of the transport sector is currently the most topical topic for the Latvian policymakers because Latvia, along with the other EU Member States, must ensure that the share of renewable energy in the final energy consumption in 2030 reaches 14 % (the target for this in 2020 is a 10 % share). Still, only 4.7 % were achieved in 2018 [54]. Renewable energy production will increase with a particular focus on solar panels, collectors, and wind energy. However, it will not be technologically possible due to storage issues [55]. Given that around 6 million tons of agricultural waste are produced yearly. The pathways and strategic priorities for the transition to a net-zero GHG emission economy provide a promising future for the development of biogas production, especially for upgraded biogas to biomethane, which is flexible both in use and storage and because its production from agricultural, industrial waste and sewage sludge protects soil, air, and water from the pollution [56], [57]. Suppose the annual biomethane production from anaerobic digestion in the European Union was 2.3 billion m^3. In that case, it is estimated that it could reach 64.2 billion m^3 by 2050 in the case of an optimized gas scenario [32].

The biogas sector is already well developed, and huge investments have been made. Still, the industry is currently highly financially dependent on state aid, and biomethane (product with higher added value) production seems to be a way to reach financial independence and profitability [32].

Biogas can be processed to biomethane and used as a road fuel or for sale on the natural gas network. Unlike natural gas, which is a fossil fuel, biomethane is a renewable fuel, which is emission neutral or even negative [58]. There are different methods for biogas upgrades, but the main aim is to separate methane from carbon dioxide to be used for heating, electricity, and fuel [59].

Since the raw gas contains approximately 65 % methane and 35 % carbon dioxide in the volume, the acquisition of biomethane is measurable on average at 63 % [60]. Therefore, it is possible to produce hydrogen from the carbon dioxide separated from biogas and used it as a transportation fuel and electricity [61], [62]. The practical efficiency of carbon dioxide conversion is 47.7 % with a hybrid Na-CO_2 cell [62].

According to the Central Statistical Bureau, 11 million m^3 of biogas was produced in 2018. If all this biogas were used for methane production, 6.93 million m^3 of biomethane would be made with 63 % efficiency. In contrast, an additional methane yield would be produced during the hydrogen methanation process from the rest of the biogas, which contains 35 % carbon dioxide. Biological hydrogen methanation could increase the biomethane yield and lower the costs for biogas upgrading to natural gas quality [63]. The efficiency of the process in a cogeneration plant right after the methanation is 30–45 % (37.5 % on average) [63], which means that if 4.07 million m^3 carbon dioxide is produced, then with biological hydrogen methanation digesters, it is possible to maintain 1.83 million m^3 of methane. Knowing that 1 litre of diesel equals 1 m^3 of biomethane, which is 10 kWh in the energy [64], the potential impact on the environment would be 1.83 million l of saved diesel fuel.

2.4. Capture by soils

Carbon sequestration comprises several techniques that aim to reduce CO_2 emissions and CO_2 concentration in the air [54]. Such methods are also called Direct Air Capture (DAC), Direct air carbon dioxide capture and storage (DACCS), and Carbon dioxide removal (CDR). Carbon sequestration by using these techniques is of vital importance. It has been reported in the AR6 IPCC [55] that without them, it is impossible to limit global warming to 1.5 °C in the Shared Socioeconomic Pathways (SSPs), where sustainable development and international cooperation are ground rocks.

Carbon sequestration by agricultural-related products and techniques is under the umbrella of biological CDR methods [55]. They aim to increase carbon storage on land by boosting primary productivity while reducing CO_2 in the atmosphere. Within CDR methods, some forest-based ones (such as afforestation and reforestation) are not risk-free [56] and are susceptible to droughts, fires, plagues, diseases, and others [57]. Therefore, the IPCC has placed a high confidence level in other alternatives for carbon sequestration, such as secondary forest regrowth, non-forest ecosystems restoration, and improved practices in agriculture and grasslands [58]–[61].

Furthermore, improving agricultural management practices can offset soil carbon losses by fixing a large share of the historically lost carbon back in the soil [62]. Some of the most effective enhanced agricultural methods to increase soil carbon content are the crop rotation cycles and the use of crop cover to avoid periods of bare soil [58], [63], [64], residue management and grazing optimization [65], [66], agroforestry, reducing grassland conversion, recycling of crop's nutrients and the use of irrigation [67]–[69]. These methods can also improve soil fertility and minimize nitrogen emissions unless an increase in fertilizers is employed [67], [70].

Still, many other methods can be classified as carbon sequestration but are not necessarily linked to agricultural practices. These can include using biochar to improve soil quality and crop yield [71], [72] and enhance the water holding capacity. Peatland restoration is another technique for increasing the land area of CO_2 sinks. However, it increases methane emissions from the created anoxic conditions [73]–[75]. Finally, bioenergy with carbon capture and storage (BECCS) is a technique counting on the carbon neutrality of energy production. It relies on the idea of bioenergy production, where the amount of CO_2 emitted during the combustion is as much as the carbon fixed in the growing biomass used as feedstock [76], [77]. BECCS claims more importance if such emissions are also captured and stored, creating a net negative emission effect in the atmosphere [78].

Overall, there are many CDR methods for carbon sequestration, with a broad spectrum of effects on the soil and water quality that might affect crop yield and biodiversity.

Nevertheless, many of these methods have proven to bring further benefits to natural ecosystems while promoting harmful emissions.

2.5. Perennial plants

Perennial plants make most of the planet's plant species, yet those grain crops for human consumption are not. Annual plants die each year and must be replanted, shortening the carbon cycle time in those areas where they are grown. However, there exist options to grow grain from perennial crops, as is the case for some oilseeds and cereals able to grow in deserts shrubs or seawater [79].

The main advantage that perennial crops bring over annuals is their capacity to distribute more resources underground than in the seeds [80], making these plants a perfect candidate for soil carbon sequestration. Moreover, some perennials can also grow sizeable underground, providing additional ecosystem services such as erosion reduction and a decrease in water and nutrient losses [80]. Thus, a shift to perennial grain crops has been encouraged in the last two decades as part of sustainable agriculture practices [81], [82].

But perennial crops for grains are not the only alternative for carbon sequestration in agriculture. Perennial grasses can also be used in multifunctional agriculture. Those additional non-conventional products can provide ecosystem functionalities and renewable energy production and promote sustainable development in rural areas [83]. The main setback of these crops is the early stage of domestication and development, which means an unexploited potential for carbon sequestration.

Also, perennial grasses can be used to enrich the soil by the conversion of croplands to permanent pastures, which inevitably results in higher carbon fixation in the grounds. Additionally, perennial grasses can reduce soil organic carbon via erosion cover if compared to annual grasses [84]. Also, perennial grasses and crops are more resistant to unfavourable climate conditions thanks to more robust storage structures like roots and rhizomes, making them an excellent alternative to improve agriculture resilience and food security [84], [85].

In conclusion, perennials are a promising alternative to boost carbon sequestration and agriculture multifunctionality while delivering additional ecosystem services.

2.6. Agroforestry

Agroforestry is a practice where perennial tree and shrub planting is combined with crops and/or animals in the same unit of land [65]. Although the term 'agroforestry' is relatively new, the practice is ancient and should return to farmers' daily practices today [66].

It is one of the ways to ensure the self-sufficiency of agriculture by reducing the consumption of fossil resources and increasing the extraction of various products. As globally agroforestry is practiced mainly by smallholder farms [67], it could be a solution in Latvia's case because 26 % of agricultural lands are owned by smallholder farms [22] that might not be able to invest in new technologies. In contrast, it would be possible to enhance income generation and security with an agroforestry system.

It is considered a dynamic and ecologically based system that diversifies production and increases social, economic, and environmental benefits [66]. It has been proved to reduce soil erosion and improve soil condition, increase resilience to weather changes [69], and increase biodiversity and carbon capture by trees and soils [68]. When tree species are deliberately planted, such a system can not only provide many benefits for crop cultivation but also improve agriculture productivity by providing additional products, like fruits, berries, and nuts, also fuelwood, which allows reducing dependency on local forests and if livestock is involved in the system, it provides fodder [69]. In livestock agroforestry systems, trees can serve as a shelter from winds and heat, which is especially important for dairy cattle to increase milk yields; also, depending on the tree species, it can provide additional feed full of minerals and protein [70].

But as agroforestry leads to a generation of an ample amount of agroforestry waste, biorefinery must be considered for effective management of residues in products with higher added value as biofuels, fertilizers, and biochar and industrial chemicals [71].

3. METHODOLOGY

To achieve the goal of this research – identify carbon farming solutions for Latvian conditions and determine their importance in reducing GHG emissions, multi-criteria analysis method TOPSIS was used. The TOPSIS method is one of the methods that allows determining the exact value of criteria to compare different units with great success. As mentioned above, this paper compares 6 carbon farming options and 5 different parameters were considered – 1 for economic feasibility, 2 for environmental friendliness and 2 for technological aspects – opportunities for the amplitude of methods implementation in real life, and they were weighted equally. To evaluate, which parameter is the most important in the selection of raw materials, industry experts voted and determined the percentage of each parameter. The TOPSIS method is based on 7 main steps:

- Demonstrate a performance matrix,
- Normalize the decision matrix,
- Calculate the weighted normalized decision matrix,
- Determine the positive ideal and negative ideal solutions,
- Calculate the separation measures,
- Calculate the relative closeness to the ideal solution,
- Rank the preference order [72].

The TOPSIS method used in this work to make a decision was 'The classical TOPSIS method for a single decision maker' [73]. During the first step of the research, data collection and analysis, including systemic review of scientific literature were obtained. During the second step, technical, economic and environmental data were used for multicriteria decision making process. Then values of indicators were set and after the normalization and weighting of indicators, rating and evaluation of carbon farming practices in Latvia was conducted. The methodological algorithm of the research is shown in Fig. 3 [74].

The methodological algorithm was applied on case study of Latvia, but it can be used for a variety of studies that need to find the best solution, depending on these criteria [74].

As one of the criteria for the TOPSIS analysis, the area allocated for this process already in Latvia without making any improvements or expansions was accepted. Also, the potential area is determined in order to find out the possible potential of the carbon farming methods not only in existing territories for these processes, but in the future, expanding the management of wider territories with sustainable practices. Since agricultural data in Latvia is relatively rarely updated, the used areas of 2016, indicated in the statistical databases, were accepted. Since the data on the extent of capture by soils application in the territory in Latvia is not known, the area allocated for it is currently accepted as the entire area used for farming, since the scope of application of this practice is very wide, but it has a huge potential for improvement at the same time. The areas required to produce biogas and biomethane were calculated if biogas was 100 % produced from the manure of agricultural animals currently present in Latvia, considering the area needed for pastures, as well as the area needed to produce the necessary food for these animals. Expansion of biogas and biomethane areas is not accepted because biogas and biomethane are products produced from a waste product and not as a primary product, therefore the development of this method will not be a determining factor to increase the number of farm animals in enterprises. In order to roughly determine the currently used area for biogas/biomethane production, the amount of energy produced in 2016 from biogas obtained in Latvia was determined [80] and taking into account how much yield can be obtained from 1 ton of the respective type of manure [51], it was calculated that only 16.2 % of the manure resource available in Latvia is used. Accordingly, the currently theoretically used territory has been equated to the amount of biogas production. The potential expansion site for such practices as agroforestry and perennial plants is assumed to be the unmanaged Latvian scrubland.

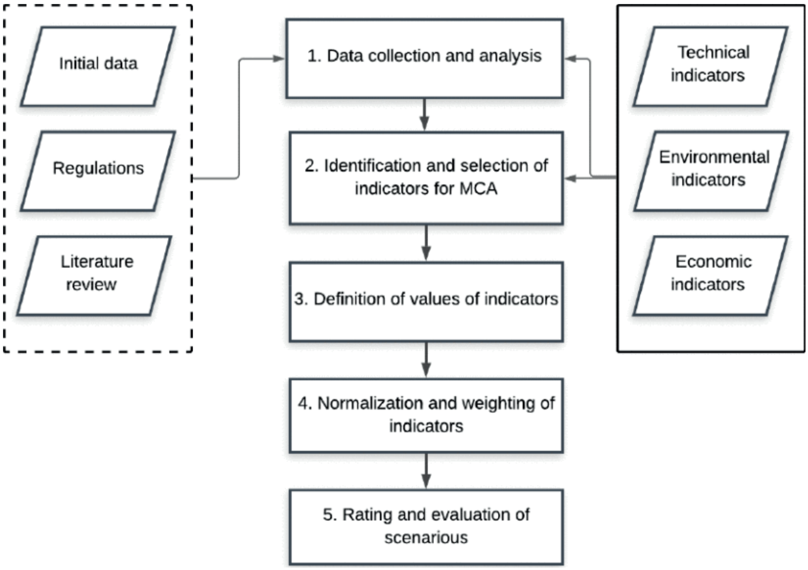

Fig. 3. Concept of the methodology [74].

One of the most important criteria for the development of these methods is the ability to attract the budget, because in practice, the introduction of new methods very often leads to financial losses for the farmer in the first years of transition, which is a possible determining factor why farmers choose to work with the previous methods, fearing to accept the risk. Therefore, to determine the available budget, the information was taken from Latvian Common Agriculture Policy (CAP) Strategic Plan 2023–2027 and information of Cohesion funds for Biomethane development.

As another important criterion, the amount of GHG emission sequestration in kilotons within one year of each method in the currently allocated areas was adopted. Since there is no exact data on how much emission occurs in these processes/sectors, the calculations were made based on assumptions from scientific publications. By improving and obtaining more accurate data on the agricultural sector of Latvia, this calculation should be improved by replacing assumption calculations with real data.

TABLE 1. VALUES FOR TOPSIS INDICATORS

Carbon Farming method	**Area, year 2020, ha**	**Potential area, ha**	**Budget, EUR**	**GHG emission sequestration in the existing areas allocated for this measure, ktCO$_2$eq/year**	**Potential GHG emission sequestration, ktCO$_2$eq/year**
Zero tillage	12 818 [75]	370 000	5 550 000 [76]	8.2	595.0
Minimal tillage	68 388 [75]	370 000	5 550 000 [76]	27.9	377.3
Biogas	180 216.1	1 112 445	0	61.6	380.1
Capture by soils	2 285 477 [77]	2 285 477	16 688 447.8 [76]	119.2	119.2
Perennial plants	28 827 [77]	103 829	15 520 000 [76]	103.8	373.8
Biomethane	180 216.1	1 112 445	61 000 000 [78], [79]	61.6	380.1
Agroforestry	0	103 829 [77]	4 055 000 [76]	0	37.4

Since zero tillage predicts a 41 % emission reduction, while minimal tillage 26 % compared to conventional [28], data from conventional maize cultivation were used to calculate the estimated annual CO_2eq reduction [81]. The current potential of biogas and biomethane is calculated by considering IPCC Default GHG emission factors and average N excretion per head of animal per year. However, it should be taken into account that the real emission reduction would be much higher, because this calculation takes into account only those emissions that are prevented by managing agricultural animal manure, while if the calculation were done differently – not according to the usable area, where the reduction of GHG emissions depends in the most direct way on the territory to be used, but on the possible consumption of biogas/biomethane in Latvia, if the use of natural gas and fossils were completely replaced by biogas and/or biomethane (according to the potential amount that can be obtained, it is possible to make sure that this is a realistically achievable goal in the case of Latvia). Using Central Statistical Bureau data, which indicates that in 2016, natural gas consumption was 1371 m^3 [82], and EPA calculator [83], it is calculated that in 2016, 29 397 tons of CO_2eq were generated due to the consumption of natural gas, which means that if biogas were used, emissions would not only be prevented by 100 %, but they would still be negative, as the use of biogas achieves a 240 % reduction in emissions compared to fossil resources [84] and 64 % compared to the natural gas in energy [85], while for biomethane 202 % to fossil fuel use in transport [84].

Accepting the application of willow biochar in the entire area of agricultural arable land in the current territories, as well as knowing that Willow biochar could compensate 7.7 % of annual agricultural greenhouse gas emissions [86], however, in 2018, soil cultivation in Latvia generated 1547.4 kt CO_2eq emissions [87], which was the largest sub-sector of GHG emissions in the agricultural sector in terms of emissions. It can be seen that the possibilities of sequestration could be as much as 119 kt CO_2eq per year, but it should be noted that this calculation is idealized without in-depth research on those areas where such application of willow biochar would not be desirable. However, taking into account the wide range of capture by soil methods, we accept it as an example calculation for all agricultural lands, which would be possible to achieve in the entire territory. Perennial plants can sequester about 3.6 tCO_2/ha/y [88] and knowing the currently used territory, the positive impact of the perennial plant on the environment can be calculated.

By calculating how much it would be possible to potentially sequester GHG emissions using all the resources available for the specific method, it is possible to see how big the opportunities for reducing emissions are provided by the implementation of positive agricultural practices. In this calculation, only those emissions that can be prevented as a result of manure management are taken into account in the biogas and biomethane potential. It does not include the emission reductions that would result from using digestate as fertilizer, so it should be noted that the true benefit would be much higher.

4. Results

During the analysis of the literature, six possible carbon farming methods were selected, which could be applied to Latvian conditions and would be in accordance with Latvia's National Energy and Climate Plan. The choice was based on the European Commission Report about Sustainable Carbon Cycles and Latvia's Common Agriculture Politics (CAP) Strategic Plan. These methods can also be used in other countries with different levels of agricultural development.

In this article zero and minimal tillage was mentioned as one of the solutions, as it would mainly work as a method to reduce emissions due to significantly reduced diesel consumption and mineral fertilizers. Carbon sequestration with soils was considered and perennial plant cultivation in order not only to capture carbon but also store it. Whereas biogas production is already existing, but an effective method of preventing agricultural waste emissions and producing a valuable and safe fertilizer. However, biogas development into biomethane is essential to maximize added value and prevent also other sectors (such as transport) emissions. The agroforestry sector is suitable for smallholder farms to increase carbon sequestration and storing in both soils and trees, reduce resource consumption and thereby emissions, and increase income, however, it must be in line with the foundations of biorefineries and focus on the efficient use of resources to achieve environmental, economic, and social goals. These methods are theoretically proving to be sustainable farming methods, which could possibly be introduced with funding for carbon farming, to ensure not only environmentally sustainable management in the future, but also the economy, to reduce costs and maximize local agriculture sector competitiveness.

The TOPSIS analysis results confirm that by current area, budget, and environmental effectiveness, the biggest potential is for such Carbon Farming methods as capture by soils, biomethane, and perennial plants.

TABLE 2. FINAL RANK FOR CARBON FARMING METHOD POTENTIAL

Final Rank	Carbon Farming Method
1	Capture by soils
2	Biomethane
3	Perennial plants
4	Biogas
5	Zero tillage
6	Minimal tillage
7	Agroforestry

5. Conclusions

Although only six of all possible solutions were analysed, the obtained information proves that these methods have a high potential in moving towards sustainable and emission-neutral agriculture.

The TOPSIS analysis results confirm that by current area, budget, and environmental effectiveness, the biggest potential is for such Carbon Farming methods as capture by soils, biomethane, and perennial plants. As biomethane production is most directly related to biogas production, as well as zero tillage and minimal tillage to carbon capture by soils, it reaffirms that all these methods are interrelated and important for moving towards sustainable agriculture. Agroforestry in Latvian conditions got the lowest compliance in this rank, however, perennial plants received a relatively high ranking place.

Not only these carbon farming methods, but also calculations can be used in other countries with different levels of agricultural development. Since the calculations were made based on assumptions from scientific publications, it is recommended to reconstruct these estimates using accurate data if available.

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The role of energy management in the agricultural sector: key prerequisites and impacts

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Abstract. Agriculture is one of the most energy-consuming sectors in the EU's economy. Implementing sustainable agriculture to reduce GHG emissions and increase energy efficiency through energy management is a crucial strategy to tackle climate change. In this paper, the role of energy management in the agricultural sector is studied, and experiences from Europe and the world have been considered. Literature analysis regarding the chosen topic has been conducted, including the methodology of energy management plan development and its implementation in the case study of Latvia. Data from Latvia's agricultural and other sectors have been analysed and compared. Latvia's Inventory Report regarding GHG emissions in the agricultural sector was reviewed, and all emission sources in the agricultural sector were highlighted. The primary purpose of the study is to find out if energy management were introduced in an agricultural company, what would be the potential GHG emission, energy savings and additional advantages. Two companies working in Latvia were surveyed, and potential emission and energy consumption reduction measures in agriculture that would be applied to companies were developed. The research showed that by implementing the basic principles of energy management, it would be possible to reduce the average energy consumption by 17%. If measures are applied to reduce GHG emissions from agricultural companies, the average emissions would be reduced by 43%.

Key words: agriculture, benchmarking, indicators, energy efficiency, GHG emissions, sustainability.

INTRODUCTION

Energy production and consumption is the primary source of greenhouse gas (GHG) production not only in Latvia but also in Europe (Agency, n.d.), (Intergovernmental Panel on Climate Change (IPCC), n.d.). In 2020, the energy sector was the largest source of GHG emissions, generating 64.8% of total GHG emissions in Latvia, including indirect carbon dioxide (CO_2) emissions. Part of these emissions was created by the agricultural sector (Center of Environment, 2022). In addition to energy emissions, the agricultural sector generated 21.5% of total emissions in Latvia in 2020, including indirect CO_2 emissions (Center of Environment, 2022).

Energy consumption within the agriculture sector and its greenhouse gas emissions are essential topics to policymakers, as agricultural activities must meet food safety objectives and ensure proper economic, environmental, and social impacts (Streimikis et al., 2022).

The issues of energy management and the amount of produced emissions are also topical since the European Union (EU) has set the goal to reduce GHG emissions, including in the agricultural sector. Energy management and agriculture can be linked together since the agricultural sector uses energy and generates GHG emissions, which can be reduced by implementing resource management measures. Within the framework of the EU's Climate and Energy policy, the member states of the EU must achieve a reduction of greenhouse gases of at least 55% by 2030 (including agriculture, land use, and forestry). Additionally, the member states must achieve at least 27% in the share of renewable energy compared to 1990 ('The 2030 climate and energy framework - Consilium,' n.d.).

To reduce impact on the environment and economics, wise and practical resource management is necessary at all supply chain stages, as well as proper measures of impact reduction are advisable.

As surveys show, with an increase in manufacturing intensity, the amount of produced GHG emissions increases simultaneously (Bais-Moleman et al., 2019). GHG emissions will only increase as production increases if the company's management is not effective and sustainable, for instance, when in a livestock farm, no management system controls cattle, their feed, and manure, as well as energy and fuel consumption. Efficient livestock farms must have a resource management system designed and planned to reduce greenhouse gas emissions (Fiore et al., 2018). Thereby the agricultural sector should introduce low-emission practices and effective methods, for example:

Agricultural practices, which would preserve lands' fertility, increase organic matter content and release atmospheric carbon;

Better animal health and welfare management would reduce the cattle's infertility and increase their comfort level and health condition, which would also increase productivity (Fiore et al., 2018; Batlle-Bayer et al., 2019);

As agricultural product manufacturing and land-use change in land cultivation would significantly increase the amount of greenhouse gas emissions (Yan et al., 2017; Rose et al., 2019), shifting towards sustainable agriculture by introducing integrated farm management (Shen et al., 2022);

Reducing GHG emissions through the use of urease inhibitors (Adu-Poku et al., 2022);

Implementing common agricultural policy (Bradfield et al., 2022).

Carbon dioxide (CO_2) is claimed to be the most critical GHG emission in the energy sector and CH_4 and N_2O (Priedniece, Kirsanovs, Freimanis, Veidenbergs, & Blumberga, n.d.). Li et al. (2016) examined and analyzed the main drivers of energy-related CO_2 emissions in various European agricultural sectors. Two main directions have been studied in the mentioned research: 1) Index Division Analyse (IDA) that has been supplemented with Shapley Index and is used to identify significant CO_2 emission drivers; 2) Slack-based model (SBM) was applied to rate environmental performance of European agricultural sectors. Applying these technologies makes achieving environmental efficiency and shadow price measures possible, encouraging discussions regarding CO_2 emission reduction activities in the agricultural sector. Because of the importance of GHG emissions, an integrated approach to CO_2 analysis is developed based on advanced decomposition and efficiency analysis models. The research covers eighteen European countries, and the applied methodology divides installments into CO_2 emissions in regions and factors (Li et al., 2016). The results of IDA showed that the reduction of energy intensity is the leading factor in reducing CO_2 emissions. The lowest carbon shadow prices were observed in France, Finland, Sweden, Denmark, the Netherlands, Poland, and Belgium, thereby having the highest CO_2 emission reduction potential. Also, measures directed at increasing energy efficiency are the most profitable way to reduce the amount of CO_2 (Li et al., 2016).

To reduce GHG and NH_3 emissions, optimizing the new livestock spatial management system and using it as a basis for future policy success is necessary. Instructions for the policy and farmers should concentrate on properly managing manure and livestock feed and optimizing industrial production systems and pig and poultry sectors in suburban areas (Aan den Toorn et al., 2021; Jahangir et al., 2022; He et al., 2023). The United Kingdom has developed a national strategy that states that by 2030 greenhouse gas emissions need to be decreased by 50% compared to 1990 (Rose et al., 2019). It was evaluated that technological improvements in the agricultural sector are required to achieve this goal by reducing livestock farming production intensity by 30% (Rose et al., 2019).

Sufficient animal feed and manure management can reduce methane and nitrogen oxide emissions in the agricultural sector (Escribano et al., 2022; Hossain et al., 2023). All agricultural segments have management possibilities to reduce the negative environmental impact (Bumbiere et al., 2022). Lovendahl et al. wrote that GHG emission reduction is possible if different types of cattle are chosen for cultivation - the type whose genetics have been modified and improved, making the nutrient digestion process faster and who, during their metabolic processes, produce less methane (CH_4) (Lovendahll et al., 2018).

Agriculture is Latvia's second most significant source of GHG emissions ('Ministry of Agriculture of the Republic of Latvia LATVIAN AGRICULTURE 2020,' n.d.). The agricultural sector emitted 21.5% of Latvia's total greenhouse gases in 2020 ('Ministry of Agriculture of the Republic of Latvia LATVIAN AGRICULTURE 2020,' n.d.). Latvia has developed a national-level strategy to increase energy efficiency and decrease GHG emissions ('National Energy and Climate Plan for 2021–2030 | Ekonomikas ministrija,' n.d.). In Latvia, 9.1% of all agricultural lands are biologically or organically cultivated, and the product market is still growing. It is one of the good examples of effective land cultivation and low GHG emission levels. The Rodale Institute states that regenerative organic agriculture and its managing practice is a potentially important tool for distributing more than the current global annual emissions and for changing the greenhouse effect ('Regenerative Organic Agriculture and Climate Change A Down-to-Earth Solution to Global Warming,' n.d.). The current diversion of soils and pastures to regenerative organic farming is expected to lead to 111% of annual carbon emissions, leading to annual negative emissions ('Regenerative Organic Agriculture and Climate Change A Down-to-Earth Solution to Global Warming,' n.d.). Scientific research is devoted to traditional farming methods by introducing crop and many plant species rotation to preserve land fertility and natural growth conditions and supply residents with local food in an innovative area (Niu et al., 2019). There are many recommendations for controlling weeds and other pests, ensuring plant nutrients, and reducing energy consumption (Saldukaitė et al., 2022). Plant rotation, correctly and well-defined soil purity, respected ecosystems, and natural plant growth conditions are the main principles of successful plant cultivation in an organic agricultural system (Morugán-Coronado et al., 2022; Saldukaitė et al., 2022). Farm experience shows that suitable results may be achieved in the long term and strictly follow organic farming principles (Verburg et al., 2022).

This study is carried out to develop knowledge on achieving a higher reduction of GHG emissions by looking at two levels - sector and company. The study results in a decrease in GHG emissions, therefore helping to achieve EU targets to reduce GHG emissions in the agricultural sector. This research aims to measure the potential energy and emission savings from the implementation of energy management actions and to propose the framework for an energy management system in the agricultural sector on a company level. All segments of agricultural activity have management options that can reduce their environmental impact. Therefore, awareness of the basic principles of energy management in agricultural companies should be promoted, and informative measures on energy management and reduction of GHG potential should be implemented.

METHODOLOGY

The methodology was based on the IPCC guidelines, written in 2017–2018. The year 2005 was compared to 2015 to see the increase in emissions in the agricultural sector. In analysing the agricultural sector, the bottom-up approach for evaluating impacts can be helpful; for example, Adewale et al. (2019) used an agricultural carbon footprint to examine the impact of two farms. Blancard and Marti (Blancard & Martin, 2014) used Data Envelopment Analysis to analyze farm energy efficiency, and Hosseinzadeh-Bandbafha et al. (2017) to evaluate fattening farms. Alonso and Guzman (Alonso & Guzmán, 2010) used the energy balance method to analyze energy efficiency in producing energy crops. Meul et al. (2007) used process analysis methodology for the calculation of energy balance in farms.

Thus, the following methods, guidelines, and manuals will be used in this publication: IPCC Guidelines, Latvian Inventory Report on GHG Emissions, and manual 'Guide for Farmers to calculate GHG at farm level and measures to reduce it'. Analysis of indicators and comparison of agricultural enterprises will be carried out, and a methodology that can be applied at a certain level will be developed.

Two specific companies were chosen because they are relevant to the research's needs, and it is appropriate to compare them. One of these companies did not apply energy management principles, which increased annual emissions, while the other involved half of these principles, and the emissions were reduced. The study demonstrated that if the basic principles of energy management in agriculture are used, emissions will be reduced several times.

To achieve the goal of this research, an algorithm of methodology has been developed (Fig. 1). It is divided into eight stages, showing the advisable actions on each level – (1) evaluation of data on GHG emissions, (2) analysis of data on the national, (3) sectoral, or (4) company level, (5) analysis of the data on energy consumption, (6) comparison of the companies, (7) improvement measures are proposed, and (8) energy efficiency measures are defined. The algorithm's first part is oriented toward identifying and analyzing the current situation. Still, the second part is identifying future perspectives, searching for possibilities, and implementing practical solutions to promote development.

As it is seen on the scheme, the methodology includes eight modules, of which three are the main ones: state level (2), sectoral level (3), and company level (4). From stages 1 to 5, data collection and publicly available data are analyzed using data analysis methods. Data are compared in stages 6 to 8, and GHG emissions and energy reduction measures are proposed. These measures are also called energy efficiency measures.

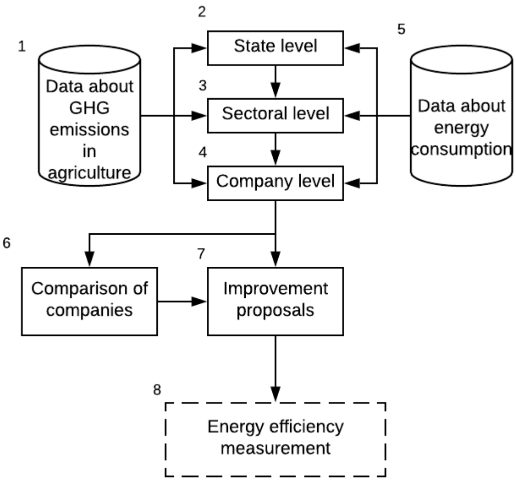

Figure 1. Scheme of the methodology.

Each year, every country in the European Union must submit an inventory report on GHG emissions developed by the IPCC guidelines related to the UN Framework Convention on Climate Change.

The inventory report includes direct and indirect GHG emissions from all sectors in the country, which are expressed in CO_2 equivalent. In the report submitted in 2017, GHG emissions were calculated for the timeframe starting with 1990 until 2015, considering the global warming potential coefficients for a one-hundred-year period.

In the Convention reporting guidelines, GHG emissions were compiled for such areas or sectors as energetics, industry and product manufacture, agriculture, land cultivation, land-use change method and forestry, and waste management.

The following subsection compares GHG emissions in CO_2 equivalent for 2005 and 2015. In the case study, data were taken from Latvia's inventory report about GHG emissions in the agricultural sector.

As the Inventory report divides the agricultural sector into several areas, this division will be further explained. On the bottom of the energy sector stands the category 'Other', in which emissions from fuel (both - for heating and transport purposes) combustion are located. These emissions are produced in all sectors - agriculture, forestry, and fishery. Unfortunately, there were no data available regarding fuel consumption in the agricultural sector, and because of that, the total amount was used and analyzed.

In agriculture, forestry and fishery usually utilize:

Stationary combustion appliances – liquid, solid-type fuel, and biomass;

District transport and other mechanic systems – gasoline and diesel fuel;

Fishery – gas and diesel fuel.

The agricultural sector is analyzed as a separate sector, and emissions are calculated in the following categories:

Agricultural lands;

Intestinal fermentation;

Manure;

Land liming;

Urea utilisation ('National Inventory Submissions 2022 | UNFCCC,' n.d.).

In Fig. 2, the division of emissions in the agricultural sector, the type of produced emissions and in what area of the sector is explicitly shown.

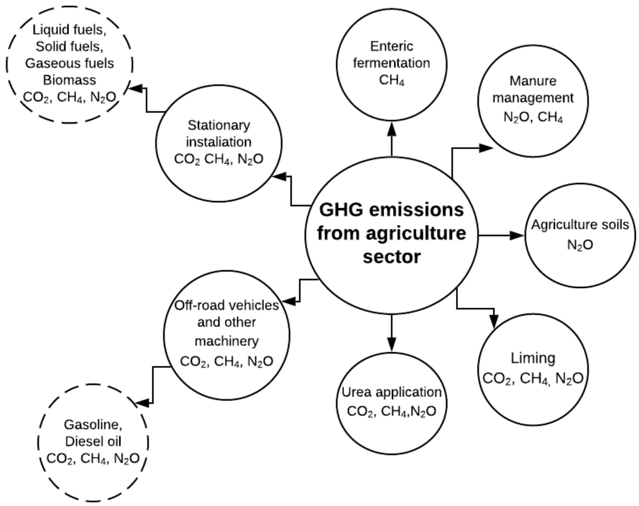

Figure 2. Breakdown of emissions from the agricultural sector.

This research aimed to measure the potential energy and emission savings from implementing energy management actions and propose a framework for the energy management system in the agricultural sector on a company level.

RESULTS AND DISCUSSION

A significant part of GHG emissions in Latvia comes from agricultural lands and cattle's intestinal fermentation, which is why, in this work, measures of GHG reduction are explicitly proposed in these areas. GHG reduction measures are described in the 'Guide for Farmers to calculate GHG at farm level and measures to reduce it.' This guidebook is based on the IPCC guidelines, and this advice can be implemented in the case of Latvia. Some of the measures are introduced in the surveyed companies.

As the literature survey shows, a significant amount of emissions comes from land cultivation. The division of produced GHG emissions in both areas is as follows:

Agricultural land:

Implementation of precise fertilization system - plan development and required technique purchase - perform soil analysis;

Use of practical techniques and technologies - combined field processing machines, zero or minimal tillage technique implementation;

Land reclamation or improvement;

Trenches around the cultivated land to avoid water pollution by fertilizers.

Intestinal fermentation:

Nutrient dosage management (plan developed and introduced);

Nutrient additive utilization to improve digestion;

Purchasing cattle that produce less methane (CH_4) in their metabolic processes.

It is worth noting that the emission division in the agricultural sector emissions does not include the emissions from transport utilization and maintenance. In the Latvian agricultural sector's emissions, fuel produces only 11% of the total GHG emissions (Center of Environment, 2022). This percentage would decrease if the proposed agricultural land and intestinal fermentation management measures were implemented.

In the case study, comparing two agricultural companies, where the main working areas are connected to livestock, has been performed and evaluated as to how much electricity each consumes and what GHG emissions are produced. Besides, for both these criteria – electricity and GHG emissions, individual reduction measures have been developed for each company.

Company 'A' acquires 1,120 ha of agricultural land, on which a biogas plant, cattle sheds, cow milking carousel machine, refrigerator premises, personnel rooms, offices, and warehouses are located. The company's 'B' inventory shows that this company owns an agricultural land area of 1,080 ha, a workshop for technical repairs, personnel premises, an office heated by using wood chips and firewood, a grain dryer, and cattle sheds.

After acquiring all the information regarding energy consumption and overall operation, several energy efficiency measures have been developed for each company. These measures include electricity and GHG emission reduction actions (Table 1).

Table 1. Inventory data

Company	'A'	'B'
Land area (ha)	1,120	1,080
Business directions	Livestock (milk), field crop production	Livestock breeding, field crop production
Livestock	948	740
Electricity consumption (GJ)	3,895.2	1,065.6
Produced GHG emissions (tCO_2eq)	3,282	2,525

The more data, the more precise and better improvements can be made. These data allow analysing which part of the company consumes more electricity and what measures could be introduced. Fig. 3 shows that, unfortunately, company 'A' has data only regarding energy consumption on the farm (cattle breeding) and the warehouse when company 'B' acquires information about all its compartments.

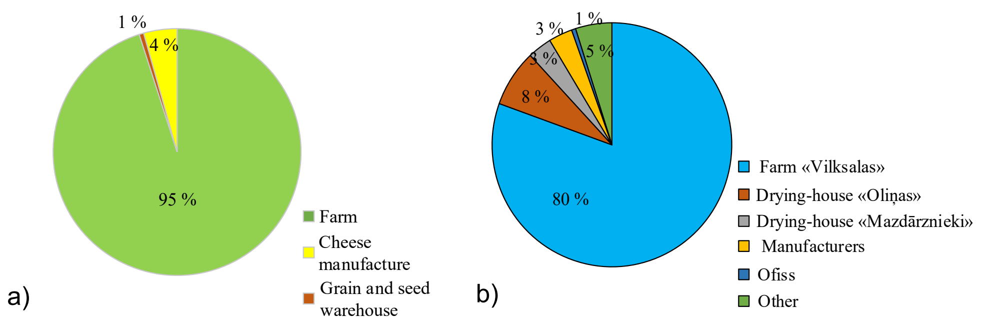

Figure 3. Share of electricity consumption by sectors in 2016: a) company 'A'; b) company 'B'.

Although the two situations are very different, depending on the information obtained, easy-to-implement proposals that do not require significant investments to increase energy efficiency and reduce GHG emissions were individually developed.

- For energy savings company 'A' was offered to start with such solutions as:
- Replacing inefficient lighting systems with new efficient ones;
- Use of fuel-efficient tires (if replaced by ten vehicles);
- Use of engine lubricants (if used in 10 vehicles);
- While company 'B' had such solutions as:
- Use of fuel-efficient tires (if replaced by ten vehicles)
- Pump replacement.

These recommendations resulted in 14% and 20% energy savings, respectively, where a suggestion for company 'A' is a transport use with a hybrid-type energy system, while for company 'B':

- Manure and agricultural residues transferred to bioenergy production facilities
- Use transport with a hybrid-type energy system
- Use of control systems for fuel economy.

If the agricultural companies implemented the GHG emission reduction measures, the emission level would decrease by about 43%. However, it is possible to conclude that there is not one specific recipe that all companies should follow because each, depending on the company's level of development, operational specifics, and applied practices, needs to individually develop a plan for reducing emissions and increasing energy and resource efficiency to achieve maximum productivity at the lowest costs and emissions.

During the research, the indicators for farm comparison, which can be used as benchmarking, were identified and compiled in Table 3.

These indicators have been developed by analyzing the literature on this topic and summarizing other researchers' assessments. Two indicators were retrieved from limited access to information on company consumption data and considering Table 3 - direct and indirect energy consumption per ton of crops and direct and indirect energy input per livestock. Table 5 gives a comparison of indicators in both companies.

Table 2. The Indicators for Farm Comparison

Indicator	Unit
Direct and indirect energy consumption	GJ ha^{-1}
Direct and indirect energy input per tonne of crops	GJ ha^{-1}
Direct and indirect energy input per tonne of product (livestock)	GJ ha^{-1}

Table 3. Comparison of Indicators in Companies

Company	GJ ha^{-1}	GJ/unit
'A'	3.30	4.1
'B'	0.98	1.4

These indicators allow us to compare different companies and analyze the benefits of energy efficiency measures and can be used in benchmarking similar size and profile farms.

Five company-level measures were identified by reviewing scientific articles and examining practices in this field of research. The most effective energy efficiency measures for the company level were determined:

Optimized fertilizer production;

Energy-saving cultivation practices;

Improved water management;

Better livestock feeding;

Use of renewable energy sources.

All found information was summarised and applied in companies, thus proving the efficiency of the developed measures. By introducing these measures, the emission level, the consumed energy and resources, also expenses can be reduced. During the research, an energy management system (Fig. 4) for the agricultural sector at the company level was developed, which can be adapted to evaluate and compare different agricultural companies.

The results have shown that using proposed indicators and benchmarking for farm comparisons is beneficial for improving the agricultural sector and reducing greenhouse gas emissions and energy consumption, leading to efficient, sustainable, and competitive farming.

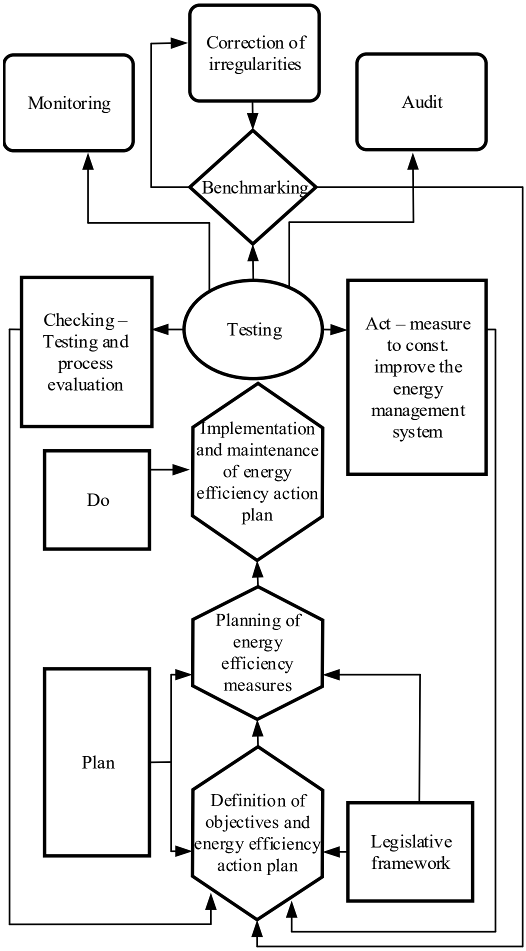

Figure 4. Energy management framework for the agricultural sector on the company level.

CONCLUSIONS

The energy management system can and should be implemented by agricultural companies. It would reduce energy consumption, optimise costs, and reduce GHG emissions. However, informative measures are required to implement these basic energy management principles in companies.

The surveyed companies should follow the initial monitoring of energy consumption data to understand where electricity and heat are consumed the most and the potential for reducing this amount. It would be advisable for agricultural companies to install an intelligent energy system. It is a sustainable energy supply system that contains information on energy consumption and options for reducing it based on monitoring the system's performance.

The energy management system can be combined with greenhouse gas reduction measures, such as organic farming and other methods and guidelines already introduced in Latvia. However, not all companies follow these guidelines. It is necessary to develop a specific policy and support program for companies to implement energy management, as implementing the basic principles of energy management or the energy system requires investment.

By implementing the energy system in an agricultural company, energy consumption in this company can be assessed, and measures can be taken to reduce energy consumption. Policy and agricultural guidelines should focus on optimizing farming and manure management.

Results show that energy efficiency improvement measures are a more effective way to reduce CO_2 emissions. If measures are applied to reduce GHG emissions from agricultural companies, the average emissions would be reduced by 43%. By implementing the basic principles of energy management, it would be possible to reduce the average energy consumption by 17%. However, it depends on the specifics of the company and what measures it can implement.

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Application of TIMES for Bioresource Flow Optimization—Case Study of Animal Husbandry in Latvia, Europe

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Abstract: As an integral part of the EU's Green Deal, the purpose of the bioeconomy is to ensure an effective transition to meet people's needs based on renewable resources while maintaining economic growth. This study undertakes the modeling of bioresource value scenarios in the agricultural sector and proposes a methodology to evaluate the possibilities of reaching a higher added value of bioresource products. The main objective of the study is the adaptation of the market allocation–energy flow optimization model system (TIMES) for analysis of high-value-added product production capacities in the livestock sector to reach an increase in added value for 2030 with the introduction of new technologies. The developed model is tested in a case study of the animal husbandry sector in Latvia. The results show which pathways are economically feasible to achieve value-added targets set for 2030. Although not all of the available resources are used due to local market limitations, there is significant potential for the use of animal husbandry resource waste, and it is possible to achieve about 62% higher cumulative added value from 2023 to 2030 with the production of new products (protein powder, wool pellets, and gelatin) in comparison with the base scenario.

Keywords: added value; bioeconomy; biorefinery; Green Deal targets; livestock by-products; optimization

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1. Introduction

Rapid population and economic growth increases the consumption of a large array of natural resources while simultaneously placing pressure on climate, ecosystems, and biodiversity [1,2]. In terms of this pressure, the bioeconomy is an essential part of sustainable development in line with the ecological needs and limits of the planet—not only can a bioeconomy approach reduce organic waste and emissions, but it can also increase food safety, reduce concerns of biomass scarcity, etc. [3]. The development of the bioeconomy also contributes to the implementation of the targets set in the European Green Deal, which foresees the use of renewable resources from agriculture and the utilization of residue and waste to produce food, feed, materials, and energy [4]. The bioeconomy strategy currently consists of two relevant stages: a medium-term scenario target until 2030 and a long-term target until 2050 [5]. It is predicted that a sustainable bioeconomy will thrive via developing a circular economy by not only introducing sustainable production but also using biowaste as a raw material for new products with the highest possible added value in production, implementing a systemic approach that reduces food waste and provides safe and nutritious food, changing the consumer's mindset towards more sustainable consumption patterns, creating new innovative uses of biological resources, and implementing a bioeconomy with a sound industrial base that reduces dependence on fossil resources [6].

Agriculture is one of the sectors that yields a great volume of biomass and biological waste for higher-added-value production, which could limit climate change, strengthen European competitiveness, reduce both energy and non-renewable resource dependence, and ensure food safety [7,8]. However, more determined legislation incentives, operational rules, involvement of stakeholders, and research and innovations at the EU (European Union) and national level are required [9]. The agricultural sector in Latvia is the third most significant sector contributing to GHG emissions, right after the energy and transport sectors, and in 2018, it contributed to 22.3% of the total national emissions [10]. Agriculture is in the most direct contact with natural resources, and this sector is directly and/or indirectly related to all sectors [11]. Since many resources used in agriculture are exhaustible, it is essential to find methods that ensure their efficient management, sustainability, and availability in the future [12]. Agriculture is an industry subject to technological processes, the application of which directly affects the production of a competitive product [13,14]. In addition, the sustainable development of agriculture can also impact other sectors where it is necessary to reduce GHG emissions [15,16].

For further development of the bioeconomy, it is relevant to expand biorefineries, as this is the multifunctional system that turns biomass into beneficial products [17]. Biorefineries depend on the amount of feedstock produced that can be used to produce higher-added-value by-products [18]. The research on scenarios for the development of biorefining and valorization of bioresources is helpful in bioeconomy policy planning. It is essential to evaluate the divergent aspects linked to the implementation of biorefineries prior to setting national bioeconomy goals for specific added value thresholds. Thus, the main aim of the research is to evaluate the contribution of animal husbandry bioresources to the development of bioeconomy on the national scale. Although agriculture plays a huge role in any economy, especially because it produces essential goods and demand is constantly growing, the growth of the agricultural sector lags slightly behind the growth of other sectors, as its potential is underutilized—currently, it is very important to increase not only productivity but also the added value of agricultural products. Moreover, this is very characteristic of agriculture not only in Latvia but throughout Europe [19]. Currently, it is also important to pay attention to the livestock sector of agriculture in Latvia because of its lower profitability compared to plant cultivation. Thus, the aim of this study is to discover the least costly solution to achieve 30% added value in the animal husbandry sector of Latvia in 2030 with the help of new products with higher added value, which are produced from current product residuals. The added value goal of 30% by 2030 (compared to the value in 2015) was selected as a very high and challenging target within the research project "Bioresource Value Model" funded by Latvia's state budget Fundamental and Applied Research Project. Such a high target would reveal the pathways for a rapid increase in the value of the bioeconomy and bioresources. The novelty of the developed model for the purpose of the study lies within the fact that, to date, there is no empirical evaluation tool that allows researchers to study the impact of new technologies on the national bioeconomy. Moreover, there is no clear economically viable pathway set for the valorization of specific agriculture residual products.

Empirical tools for the multiplex analysis of systems and the analysis of different development scenarios are applicable to shaping policy strategies. A tool that would make it possible to consider various aspects in the assessment regarding the rivalry for biomass to simultaneously meet the requirement for products in various sectors, for instance, energy, food, and medicine [20], is a significant advantage in the planning of any national policy. There is a variety of choices among existing tools for the survey of the bioeconomy, such as the energy–environment–economy global macro-economic (E3ME) model [21,22] and computable general equilibrium (CGE) models [23], but the market allocation–energy flow optimization model system (TIMES), which is often used for national-scale energy system modeling [24–28], appears to be a suitable tool to incorporate additional factors that can provide greater insight about the modeled system and provide support in the decision-making process. For example, the results from studies on homeowners' preferences of heating technologies [29], travel behavior, and travel time [30] were incorporated into TIMES energy system models. Due to this specific flexibility and broad-ranging scope that such a tool can capture, the TIMES modeling approach is used for this study.

The structure of the article is designed to systematically present research findings and their implications, including Sections 2–4. Section 2 showcases the empirical outcomes of the research, often presented through figures, tables, and textual descriptions. Here, the findings are objectively presented and interpreted. Section 3 outlines the experimental design, data collection procedures, and methodologies employed in the study to obtain the previously mentioned results. This provides readers with a comprehensive understanding of how the research was conducted and enables reproducibility. Following this, finally, Section 4 encapsulates the essence of the study, summarizing the key insights and implications drawn from the results. It also serves to contextualize the study's contribution within the broader scientific landscape.

2. Results and Discussion

The baseline scenario's outcome is represented by the flows taken from statistic databases and used as input data for the model with a correct mass balance. The bioresource flows for the base year 2015 are revealed in the Sankey diagram (see Figure 1). The amounts of material input criteria are fixed to show a historical perspective of the livestock sector. This shows that the biggest part of the obtained animal products in mass units consists of locally produced and imported milk, locally produced meat, and eggs. Wool and honey obtained in the examined mass units make up a small part of the total volume of animal products. The largest part of the milk and food produced from milk is exported, and a noticeably big part of the products produced is used for local consumption with some losses (mostly from milk production).

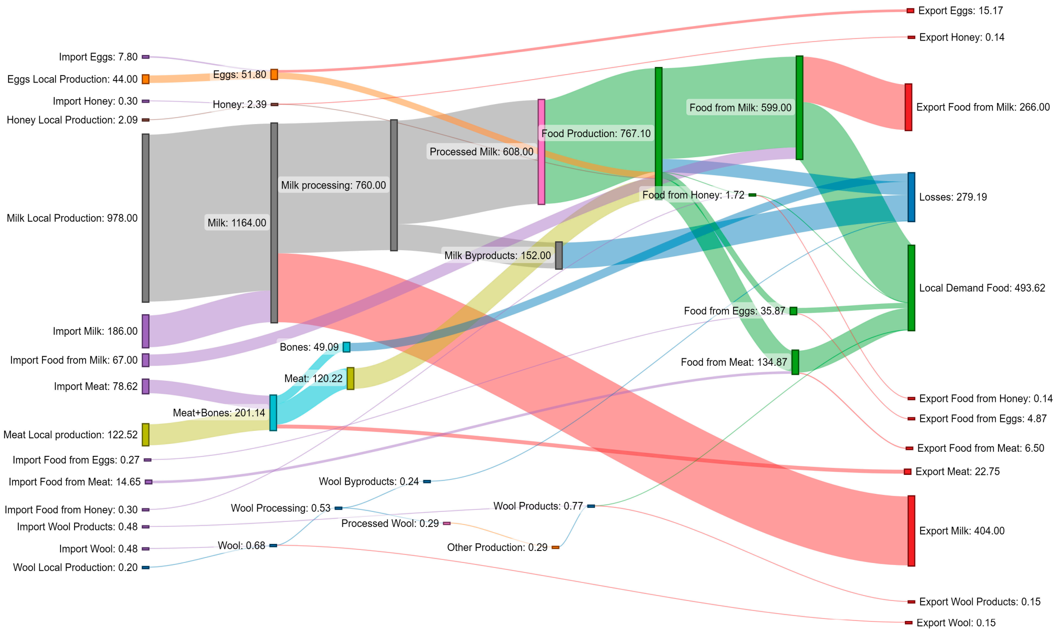


Figure 1. Sankey diagram for the base year results (2015) in thousand tons (kt).

Even after introducing new technologies, the desired result of the complete use of by-products has not been achieved yet in any scenario because of local market limitations. However, it can be observed that trends calculated by the model show an increase in local and imported commodity volumes in 2023 and 2030 compared to the base year 2015 while having a decrease in total material losses. Although only part of the by-products was used in the production of the new products, their economic contribution over the 7-year period is noticeable. When introducing new technologies, the cumulative added value is calculated to exceed the set goal of a 30% added value increase in bioresources in 2030 by more than two times (62%) in years 2023–2030 in the case where these technologies are introduced starting in 2023 (see Figure 2).

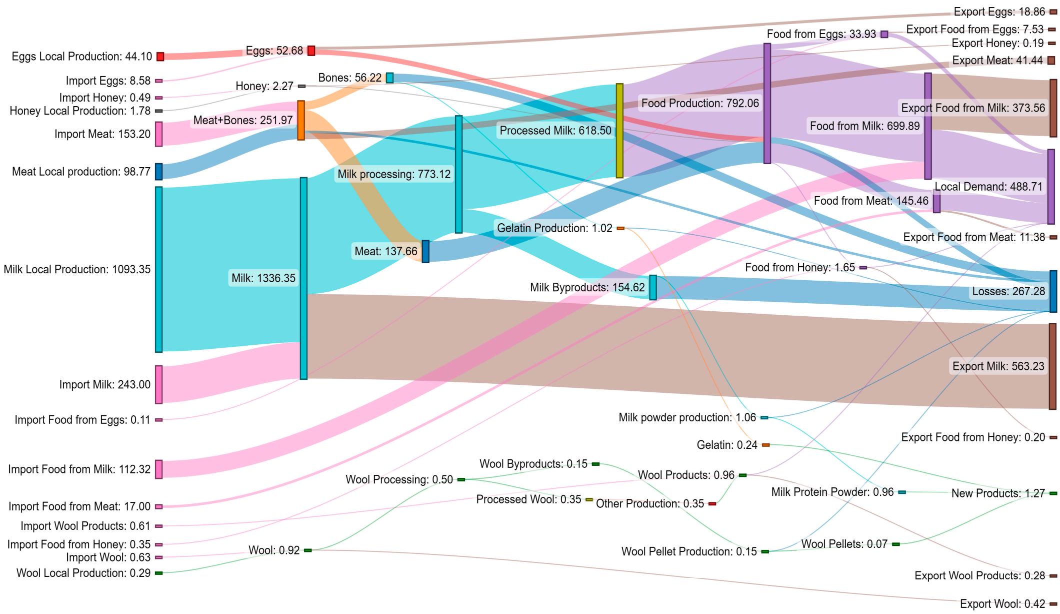


Figure 2. Sankey diagram for the results of year 2023 in thousand tons (kt).

Similarly, a Sankey diagram for 2030 with the results of the simulation, including data added on new products (gelatine, wool pellets, milk whey protein powder, and eggshell powder), is shown in Figure 3. The graph shows that flows for both domestic milk production and imported milk will increase, which are the largest flows, still followed by imports of imported dairy food and meat production. The by-products generated in the milk processing process are almost constant, which is the main source of by-products, but due to the new products, the total resource loss decreases by 33.9 kt. The final food flows show that the volume of exported milk has increased by 1.6 times compared to 2015, while food produced from milk has increased by almost 1.9 times. Other flows have also grown significantly, for example, exported meat by 2.7 times, exported wool and its products by 3.1 times, and exported eggs and their products by 1.7 times, but these flows are smaller against the overall background in mass units.

Among the new products, the model results show produced milk protein powder, gelatin, and wool pellets (see Figure 4) but no eggshell powder. The production of the new products is influenced by the efficiency and cost of the production processes and the added value per unit because the eggshell powder has a relatively low production efficiency due to the mass ratio and relatively high losses when the powder is produced from a whole egg.

The model reaches the limits (e.g., the capacity of resource application, economic viability, and demand limit) of available resources for milk protein powder and gelatin; thus, the same amount is produced every year. Protein powder and gelatin reach the available resource limits immediately in 2023, and, therefore, their production is constant. As for the wool pellets, all of the wool resources available are used to produce wool pellets. The forecasted demand for pellets, on the other hand, is 58.37 thousand tons. The pellets produced are only about 0.1% of this demand value. If forecasted demand values were removed, then all added value would be covered by milk protein powder.

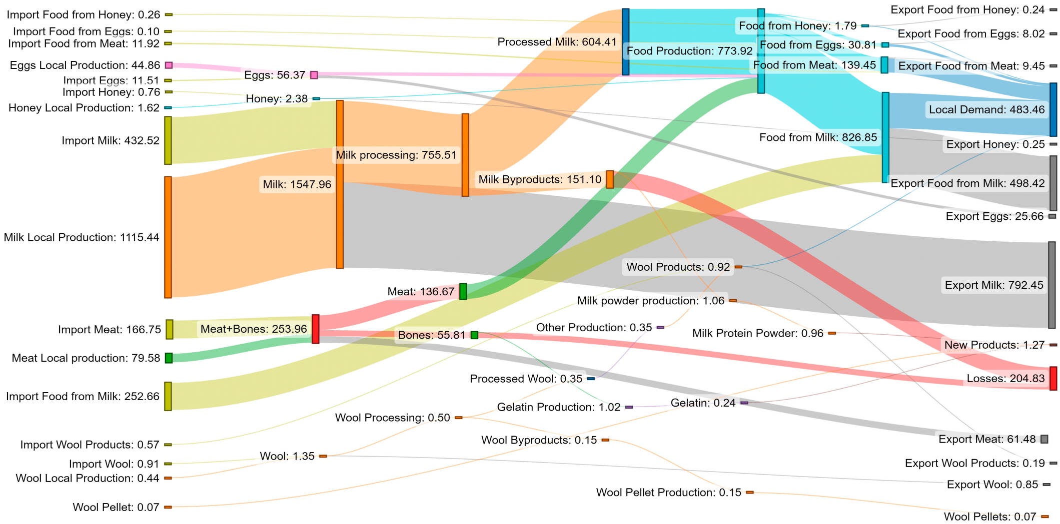
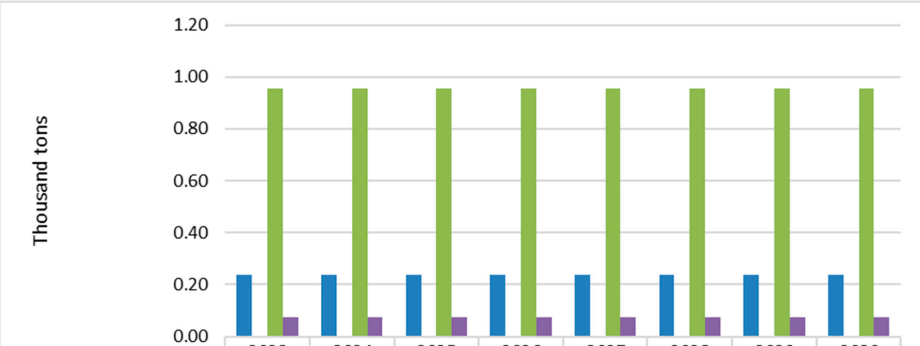


Figure 3. Sankey diagram for the results in target year (2030) in thousand tons (kt).



	2023	2024	2025	2026	2027	2028	2029	2030
Gelatin	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Egg Shell Powder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Milk Protein Powder	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Wool Pellets	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074

Figure 4. Amount of new products produced, kt.

Value added from new products as a share of total value added in different years ranges from 7.6% to 8.2%. On average, the added value is 7.9% per year. This percentage changes as the amount of other products produced changes from year to year, but the amount of new products produced remains the same each year (see Figure 5).

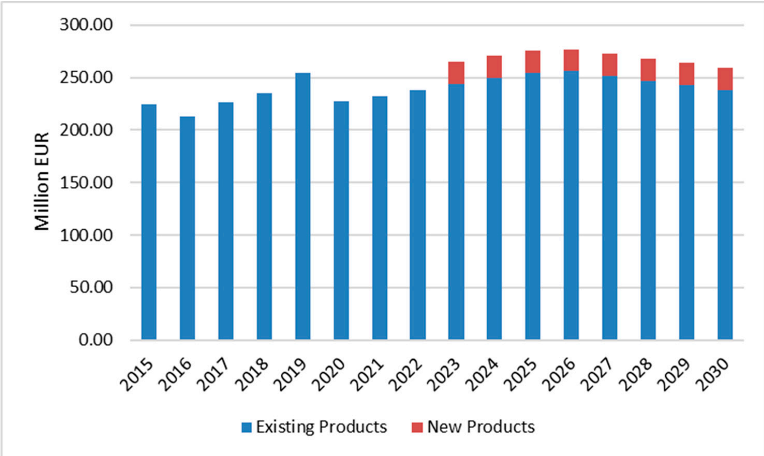


Figure 5. Total existing and new product added value, EUR million.

Figure 6 shows the added value for newly produced added-value products. In this case, milk protein powder takes up most of the value added, which is probably due to the fact that milk products constitute the largest share of food products and the added value per unit of milk protein powder is larger than that of other products.

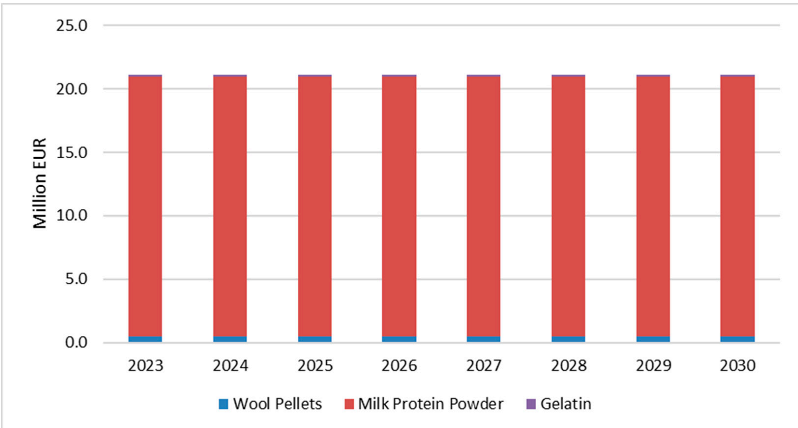


Figure 6. Added Value Structure for newly produced added-value products.

3. Materials and Methods

3.1. Modeling Approach

The selected modeling approach through TIMES allows for linking energy sector consumption and conversion technologies with other sectors [31]. The TIMES model parameters consider resource limits and costs, operating and maintenance costs of product production technologies, and the demand for specific products and also allow the definition of new parameters in the model, such as the added value of the product. Simulations of the model allow us to capture both mid- and long-term results. Besides biomass flows, the model allows us to include by-product and waste flow definitions for processes in biorefineries, and, finally, the model is an optimization model that helps to find and select the best scenario for bioeconomy development considering the least expensive solutions for various technologies. The chosen modeling approach applies optimization to discover the most economically feasible solution to reach the determined goal—to achieve a 30% added value in 2030 with the production of new products with a higher added value by introducing new technologies and using residual products as raw materials. For scenario investigation in this research, backcasting is used—it starts with the definition of the preferable future and further works backward to spot the necessary measures to reach the targets.

The TIMES bioeconomy value model (TIMES-BVM) is designed to model bioresource flows and technologies for the development of the animal husbandry sector; however, it can be modeled to research other sub-sectors in agriculture, such as cereal farming, field plant production, greenhouse horticulture, and others. The aim of the model is to help understand how the agricultural sub-sector can contribute to meeting the higher value-added goal for bioresource growth for 2030. The model addresses the development of biorefineries from the perspective of natural limits (the capacity of resource application), economic viability (technology, maintenance, and operation), and socio-economic aspects (increased salaries, etc.).

The model created in the research is used to find the most economically viable scenario for increasing the value of bioresources. It is achieved through an optimization-type simulation, which uses historical data from 2015 to 2019 and a forecast of future industry development trends as well as opportunities to use new bioresource technologies for the production of higher-added-value products starting in 2023.

3.2. Data Analysis and Inventory

The model structure is created based on the general TIMES-BVM structure, including resources (in this case, primary livestock resources such as eggs, meat, milk, wool, and honey), technologies (pre-processing and preparation of raw products; production of food, feed, and other products; and also processing of by-products), product flow (import, export, and domestic production) and demand. Processes used in the structure are divided into primary production, import and export processes, transformation activities like those in biorefineries, and product demand (see Figure 7). These elements are defined based on data from statistical databases, such as the Central Statistics Bureau (CSB) of Latvia, Eurostat and Faostat databases, those from the literature, interviews of companies, and approximations.

The model includes four bioresource stages: primary and processed resources, final product, and demand. Various technological processes are integrated for primary resource supply in terms of local and imported resources, costs, efficiency, capacity, availability, and limitations of processing technologies for primary and secondary resources. Each conversion path in the simulation of the model is calculated through an optimization approach, and the results show the best solution to satisfy the demand at the lowest cost. The results include the technical and economic characteristics of the pathways based on the model inventory. The model output is produced as a quantitative result for biomass flows and new capacity additions for technologies used in the production of products to meet the demand, the overall costs, and the overall added value of the products supplied, shown in Table 1.

The structure of TIMES-BVM requires the definition of product demand for the selected target year of simulation, and it is carried out by applying a forecast based on regression analysis according to methods introduced in the literature [32]. Input data for the request of finished products are fixed on prediction based on regression analysis for the years up to 2030. Regression analysis is performed prior to running the model. The demand for the finished product is a dependent variable in regression analysis.

The data input for resource import, export, and domestic production values is based on the extrapolation of statistical trends from 2015 to 2019 with the help of regression analysis. These values have upper and lower boundaries entered into the model in the range of $\pm 10\%$, except for meat, which has a range of $\pm 25\%$. These ranges allow tradeoffs among other processes in order to fulfill the demand within the given set of limited capacities of technologies and resources. The selected boundaries allow production to match the demand and the avoidance of model instabilities due to poor statistical data availability and quality. This assumption allows the avoidance of shortages or surpluses that are neither consumed nor exported.

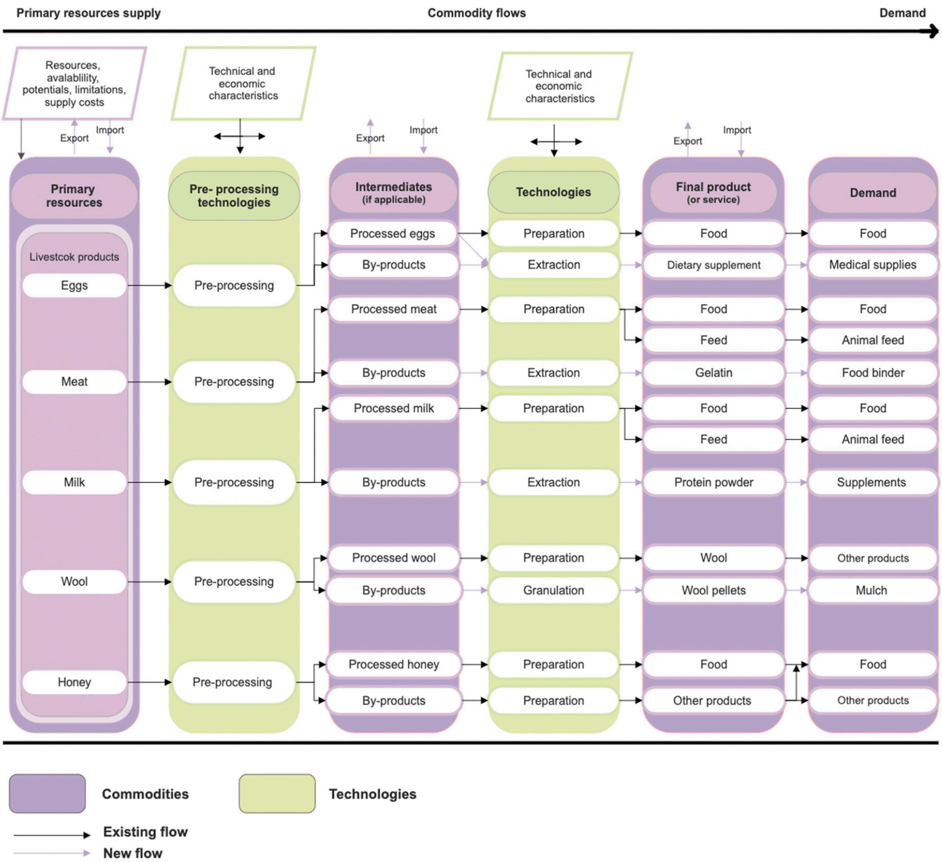


Figure 7. BVM TIMES Livestock model structure.

Table 1. TIMES-BVM model input data.

Constituent	Variable	Measure of Unit
Primary resource supply	Type	Domestic harvest/import
	Stock Cumulative Value	Thousand tons, kt
	Cost	EUR/kt
	Yearly production	Thousand tons, kTt
	Limitations	Upper/lower
	Flow	Input/output items

Table 1. *Cont.*

Constituent	Variable	Measure of Unit
Conversion (existing and new technologies)	Flow	Input/output items
	Efficiency	%
	Existing Installed Capacity	Thousand tons yearly, kta
	Utilization	%
	Investments	EUR/kta
	Lifespan	Years
	Fixed costs (maintenance and operating)	EUR/kt
	Added value	EUR/kt
	Limitations	Upper/lower
Demand	Demand value	Tkt

3.2.1. Honey

In the case of honey production in Latvia, the statistics of the honey industry are wildly inaccurate because some honey is legally sold without official accounting and without paying taxes. The approximate amount of honey produced in a certain year is determined by multiplying the average amount of honey produced in one farm by the total number of farms in operation in the given year.

According to CSB statistical data, the amount of honey produced in 2018 was 2000 tons, while according to calculations made in accordance with the method described above, it was 3809 tons, which is almost 2 times higher. For the purposes of the study, the latter amount of 3809 tons was used in the model. Since there is no record of honey consumption in Latvia's statistical database, it was assumed to be 100%—everything produced is also consumed. It should be considered that honey is not just one final product, and it differs depending on the flower nectar from which it is obtained. Thus, there are differences in both price and demand depending on the type of honey. Regardless of this factor, the price of honey is very stable, and there are no fluctuations in price observed. To increase the value added in the honey production industry, products such as honey, beeswax gums, face creams and soaps, royal jelly (nutritional supplement), propolis, and pollen (natural antibiotics) can be produced but have not been studied in this research further because of insufficient data.

3.2.2. Milk

Dairy farming in Latvia is a traditional and highly developed industry. It is one of the most important sub-sectors of the agricultural sector in Latvia. According to the CS data, the number of dairy cow herds is decreasing annually. In contrast, the milk yield from one cow shows a positive trend. In 2002, the average milk yield from one cow in Latvia was 3.96 tons [33], but now, it is already remarkably close to the average European cow productivity, which was 7.5 tons in 2020 [34]. Despite considerable progress, the Central Union of Dairy Farmers of Latvia (LPCS) claims that it is no longer profitable to produce dairy products in Latvia [29].

According to the survey of local dairy farmers, it can be concluded that for several years in Latvia, there has been a tendency to import the milk needed for dairy processing at lower prices instead of using local milk. The analyzed statistical data and forecasts based on extrapolations used as the data inputs for the model (see Figure 8) show a steady trend in domestic milk production. At the same time, an upward trend in import and export, while a downward trend is visible in domestic milk food (processed dairy products) production, which provides products with higher added value, and an upward trend is observed in exported and imported milk food products.

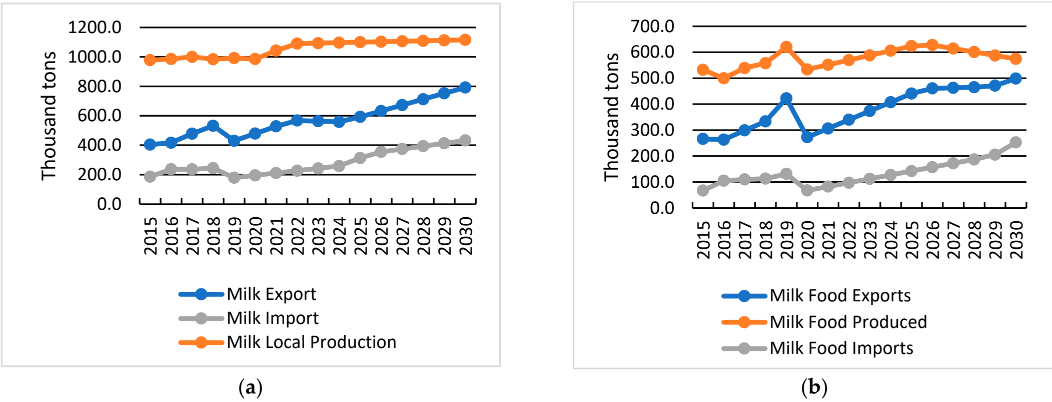


Figure 8. (**a**) Milk import, export, and local production; (**b**) Milk food import, export, and local production.

Potential products could be protein powder, agricultural fertilizer, polymers, alcohol, lactic acid concentrate, animal feed, etc. In order for each farm to find the most efficient and best solution, it is necessary to understand not only the seriousness of the situation in the development of future scenarios but also clarify the expertise required, how to assess it, and information on available public support.

3.2.3. Eggs

In the egg market in Latvia, the number of eggs laid is constantly increasing, and more is produced than is needed for the local market, so a large part is exported. The extrapolated statistical data presented in Figure 9 are used as input for the model. In Figure 9b, the forecast shows that a significant drop in domestically produced egg produce (processed products) can be expected, while the import of egg products remains constant.

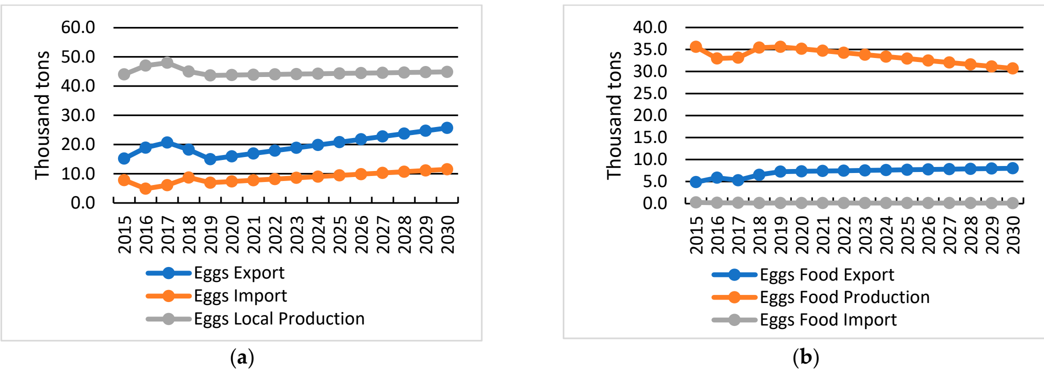
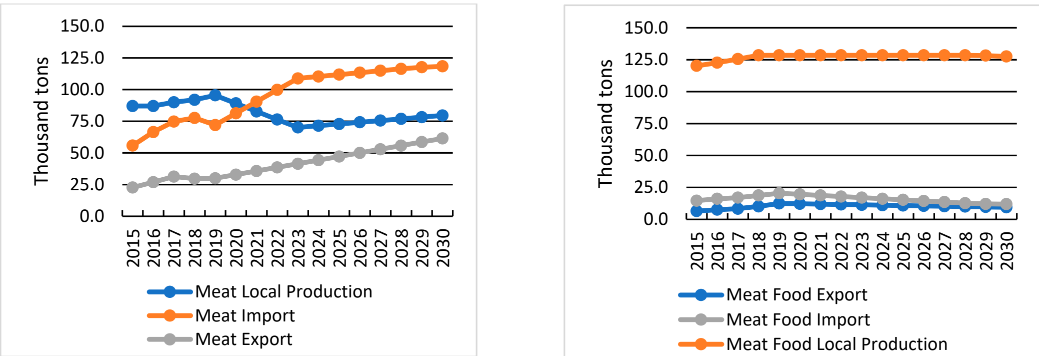


Figure 9. (**a**) Egg import, export, and local production; (**b**) Egg Food import, export, and local production.

As egg whites, yolks, and eggshells contain many valuable substances, these could be used to produce health-promoting products. Chicken eggshells consist of 95% calcium carbonate, an excellent filler in composites, which is easy to use in production due to its low specific density [35]. Since calcium builds and ensures healthy bones, egg powder, which contains substances such as magnesium, fluoride, and other minerals, can also serve as an effective calcium supplement [36]. Therefore, it is essential to explore the possibilities of producing eggs for primary consumption, export, and products with higher added value, which could benefit the development of local egg production.

3.2.4. Meat

Poultry plays an important role in the meat industry, with chicken meat accounting for the largest share. The extrapolated statistical data shown in Figure 10 are used as input for the meat section in the model. The statistical data and forecasts made show that the total demand for meat food (processed meat) in Latvia will decrease in the future (see Figure 10b). There is a significant decline in local meat (raw) production from 2019 to 2023. Although the upward trend in meat production resumes in 2024, it is slow and stagnant compared to the huge jump in imported meat volumes that can be observed already from 2020. The production of meat products (see Figure 10b) for the local market will remain almost unchanged in 2030, while the export, import, and production of meat products for processing into products with a higher added value will consequently decrease.



(**a**) (**b**)

Figure 10. (**a**) Meat Import, Export, and Local Production; (**b**) Meat Food import, export, and local production.

Potential products with higher added value considered in the model are biogas (for example, turkey tails, etc., where the fat content is particularly high), animal feed (bones, dog treats, etc.), gelatin, lime, broth, bone paste and powder, various extracts, protein of animal origin, and collagen.

3.2.5. Wool

The input data for wool (raw) used for the model are shown in Figure 11. According to the statistical data analysis and trend extrapolation, exported wool is rising rapidly, while the amount of exported wool products with higher added value is falling rapidly. Although wool imports are growing rapidly, the demand for wool product imports is forecasted to decline. Domestic wool production, on the other hand, is slowly growing, while production volumes of domestic wool products remain constant.

According to the current situation, wool export will continue to decrease, and even in local wool processing, no improvements are expected. Wool production is related to the production of sheep meat and the number of sheep. According to the statistics, there is a decreasing trend in the number of sheep in Latvia since 2017. The trend of local wool production is directly dependent on other influencing factors, such as the development of the meat market.

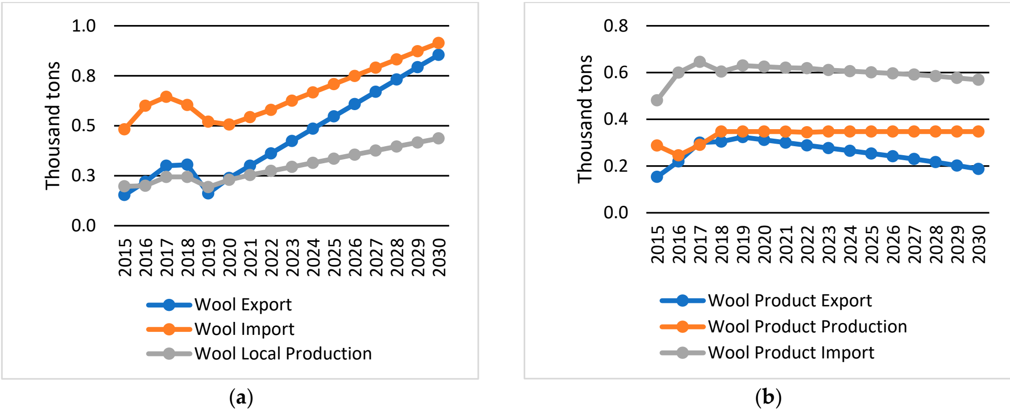


Figure 11. (**a**) Wool import, export, and local production; (**b**) Wool Product import, export, and local production.

3.2.6. New Technologies for Higher-Added-Value Products

The new technologies to produce higher-added-value products included in the model structure are:

(1) Dietary supplement production from processed eggshells;
(2) Gelatin production from meat-processing by-products;
(3) Protein powder production from milk-processing by-products;
(4) Production of wool pellets from wool-processing by-products;
(5) Production of honey-derived products from honey by-products.

The limit for the availability of new technologies in the model is set to 2023, signifying the current possible implementation of these technologies. The production amounts are limited by the available by-products and waste products from existing processes. Therefore, the production of new products with higher added value depends on the demand and thus also the local production of the conventional products. The demand was defined based on the historical average market data for these segments [37]:

- Calcium carbonate;
- Gelatin and its derivatives (excluding casein glues, bone glues, and isinglass);
- Protein concentrates and flavored or colored sugar syrups;
- Pellets and briquettes of pressed and agglomerated wood and of vegetable waste and scraps.

The added value of the item is recognized as factor costs and is established as the gross earnings of biorefineries (salaries included) for operating activities. It is estimated based on the official CSB available data on the market-added value and produced volume of goods [38].

3.2.7. Other Assumptions and Limitations

Other factors limiting the use of by-products within the model were assumptions about technologies—process efficiencies; resource and product prices and costs; and upper and lower limits on the import, export, and local production of raw resources and final products—as they influence the commodity balance and thus indirectly influence the need for resource processing, resulting in different amounts of by-products and, consequently, different amounts of new products.

While the energy efficiency of the European Union's agriculture has remained relatively constant over the years, the energy efficiency indicators of Latvia's agricultural sector show a downward trend from 2010 to 2017. The total consumption of energy resources of the agricultural sector has increased year by year since 2010, while the turnover of manufactured products has not been able to generate a sufficiently competitive economic contribution to compensate for the increase in energy consumption. To increase energy efficiency, it is necessary to implement energy management, which is the intelligent and efficient use of energy to maximize profits while reducing costs [39]. Moreover, energy management is related to the economic and environmental aspects to eliminate the inefficient and reckless use of resources, which in turn causes global warming [40]. The data used in the model and the model itself do not consider any potential benefits that could result from the application of energy efficiency measures in the agricultural sector and that could derive from the implementation of energy policy goals. Also, the impact of breeding and genetics, as well as welfare and feeding, on the productivity of production is not considered in this study.

3.3. Validation of the Results

Mass balance validation is used as a crucial element in the TIMES model to guarantee the robustness of the findings. Potential discrepancies in the representation of commodity and resource flows can be found and corrected using mass balancing. Mass balance calculation for the obtained results ensures uniformity and precision of the results obtained. The mass balance calculation is adopted from the EN 16785-2 standard "Bio-based products—Bio-based content—Part 2: Determination of the biobased content using the material balance method" [40] as shown in Equation (1):

$$\sum M_{in,\ i} = \sum M_{lo,\ j} + M_{t,\ \ out} \tag{1}$$

where:

$M_{in,i}$ is the mass, expressed in kilograms of the input commodity i entering the production process under consideration;
$M_{lo,j}$ is the mass, expressed in kilograms of the loss i in the production process under consideration;
$M_{t,out}$ is the total mass of the product, expressed in kilograms, leaving the production process under consideration.

When discrepancies in mass balance are found, additional research is conducted to determine the precise causes and probable sources of errors in the model assumptions. These could be typographical errors in data entry, insufficiency of data sources, or unrealistic modeling assumptions. Once the differences are identified, the necessary corrections can be made to guarantee a more accurate depiction of the model simulation outputs.

4. Conclusions

The study presents a novel model that helps to investigate the application of new technologies in the agriculture sector and evaluate their contribution to the agriculture sector in terms of the production of new competitive products and the development of biorefineries that have a significant impact on both agriculture and other sectors overall resource efficiency. The model shows that the production of local resources with a higher added value would bring a more outstanding contribution to the local economy. In terms of mass, however, the desired result of the maximum use of by-products was not achieved in any scenario. When introducing the new technologies starting in 2023, the local bioeconomy benefits strongly by producing higher-added-value products.

In this study, the evaluation of aspects related to biorefinery implementation is performed with the developed model in relation to the national bioeconomy goal set for a 30% increase in the added value of bioresources by 2030. The new technologies introduced in the model that create higher added value from bioresources obtained in animal husbandry are the production of protein powder, gelatin, and wool pellets. The new technologies in the model are available starting in 2023 and are used in the production of added-value products. The cumulative added value produced from 2023 to 2030 is about 62% above the added value produced by currently used technologies. However, the maximum use of bioresources has not been achieved due to assumptions limiting the production of new products in line with the market size for these products. The production of milk protein powder and gelatin reached the set market size limit. The production of wool pellets reached the maximum of what was possible given the amount of wool processing by-products. The remaining eggshell powder amount could potentially be decreased with higher eggshell powder production efficiency or higher added value for eggshell powder.

The model makes it possible to evaluate aspects related to an increase in added value empirically with a time reference in order to find an optimal scenario for the development of the agricultural sector. This can be useful for making agricultural stakeholders aware of the development of biorefineries and their positive impact on the local economy. The obtained optimal scenario can be used in national policy planning, as it clarifies which technologies are worth investing in and what agriculture residuals have the most potential to be used to produce higher-added-value products. Further research with statistical data from other sources and the introduction of more new technologies can be applied in the TIMES bioeconomy value model (TIMES-BVM) for defining more possible scenarios for the development of biorefining and development of suggestions for bioeconomy policy planning.

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Progress of the Agricultural Sector toward Climate Neutrality: Identification of Essential Stages

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Abstract: The agricultural sector's progress toward climate neutrality is of great importance not only in the climate, but also in economic and social contexts. Climate-neutral agriculture is highly dependent on innovations that ensure maximum efficient farming, which not only reduces emissions but also ensures competitiveness in the market; all of this is fundamentally influenced by well-considered policies. Due to the complicated structure of the sector, it tends to be very difficult or even impossible to determine the real obstacles that delay the progress of sustainable farming. Therefore, this research aims to create a system dynamics model using Latvia as a case study, which would not only provide an insight into the system's structure, but also identify the system's weak links and allow for the development of recommendations. The model can calculate not only the generated emissions per unit of production, but also the investments required to reduce 1 kt of CO_2eq generated, and results could help policymakers in any country to make rational, non-controversial decisions simultaneously in the context of economic and Green Deal objectives. The results of the study demonstrate that to increase economic competitiveness and reduce emissions in agriculture, the most important aspect is the ability to invest in innovations and new technologies that would achieve not only the lowest emissions, but also high productivity and competitiveness in the market. The research shows that the strategic documents emphasize manure management and improvement of feed quality, but there is an important element missing—an emphasis on thermoregulation improvements for animals. By improving feed quality, manure management, and thermoregulation all together, there was a 60% GHG emission reduction without reducing—and even significantly increasing—milk yield. In addition, in a comprehensive improvement of the new innovations, the case study company managed to increase milk yield by 69%.

Keywords: dairy farming; system dynamics; innovations; management; sustainability; GHG emissions; policy

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1. Introduction

The agriculture sector keeps an essential role both globally and in Latvia's economy, and is crucial to economic growth. However, rural areas often have enormous, but rarely fully realized economic potential. Energy efficiency trends in the agricultural sector also point to necessary improvements in the whole EU [1]. To increase energy efficiency, it is necessary to introduce energy management, which is a reasonable and efficient use of energy to maximize profits by reducing costs. In addition, energy management is related not only to the economic aspects, but also the environmental aspects, in order to eliminate inefficient use of resources, which in turn causes global warming [2]. However, the main problem is the large proportion of hard-to-reduce greenhouse gas (GHG) emission sources, which is the main characteristic of this sector [3]. Both in Europe and Latvia, the agricultural sector is one of the largest sectors producing GHG emissions (382.45 and 0.1 million tons of CO_2eq), with high potential for productivity and efficiency improvements [4,5]. Although agriculture captures carbon dioxide in the process of plant growth, emissions are also generated in many processes; for instance, intestinal fermentation processes of farm animals, manure management, agricultural soil treatment, liming and urea use, fuel use for field cultivation, energy use in various processes, etc. [6].

Agriculture is in the most direct contact with natural resources—water, land, plants, animals, natural minerals, energy—and is directly and indirectly linked to all other sectors [7]. Not only does it connect with other sectors and all kinds of resources, but the diversity of its activity also makes it a very complex, difficult sector to organize. Nevertheless, it is a very important investment both in terms of environmental and also in economic development [8,9]. Inclusive, sustainable, growth-promoting, and equitable development of all sub-sectors of agriculture could have a large impact not only on the agricultural sector itself, but also other sectors, in which it is necessary to reduce GHG emissions [10,11]. As many of the resources used in agriculture are depletable, it is crucial to find methods to ensure their efficient management, sustainability, and availability in the future [12]. It is crucial to implement energy efficiency and resource efficiency measures without simultaneously reducing productivity [13]. However, these energy efficiency measures in the agricultural sector often require large investments in new technologies, and saving on factors such as lighting intensity, heat energy consumption, and the economy of various resources is not possible, as it could potentially threaten the existence of companies due to reduced or possibly even non-existent harvests. Agriculture is a sector subject to technological processes whose application has a direct impact on the production of competitive products with higher added value [14].

Undeniably, the adopted policy has a great influence on the direction of agriculture. Although the goal and meaning of the green course are unified [15], common agricultural policy is developed individually by the member states [16]. The new common agricultural policy envisages making EU agriculture fairer, greener, more results-oriented, as well as guaranteeing stable incomes for farmers and protection against bad harvest years and market price fluctuations [17]. The direction of the transformation is influenced by different strategies.

Climate Neutrality Strategy 2050 aims to achieve climate neutrality by 2050 through improvements in key GHG-emitting sectors [18]. The action measures to achieve the goal planned in the strategy are to achieve resource-efficient agriculture that produces products with high added value and high productivity, and to increase agricultural investment in bioenergy. The "Farm to Fork" strategy aims to make food systems environmentally friendly (neutral or even positive impact); not only help to mitigate climate change, but also adapt to it; reverse the loss of biodiversity; ensure food security and equity; foster competitiveness; and promote a fair trade [19]. It sets specific targets, such as halving the use of pesticides, reducing fertilizers by at least 20%, increasing the area of organic farming by 25%, and reducing antimicrobials used on farm animals by 50%. Another one is the new Biodiversity Strategy for 2030, which is a comprehensive, systemic, and ambitious long-term plan to protect nature, stop ecosystem degradation, and restore degraded ecosystems [20]. In the light of the Green Deal and its 'Farm to Fork' and 'Biodiversity' strategies, the EU aims to find new ways to decrease GHG emissions through a new approach for Europe—the EU Carbon Farming initiative—stating that farming practices that remove CO_2 from the atmosphere should be rewarded in line with the development of new EU business models [21]. Furthermore, within the framework of the National Energy and Climate Plan (NECP) for 2030, there is a desire to achieve sustainable land management, sustainable farming of agricultural crops and farm animals, respect for the climate, nature protection, improved economic and social aspects, and to make a significant contribution to bioenergy in the field, all without endangering food security and CO_2 sequestration, as well as following the cascade principle; in order to achieve high productivity through the efficient use of bio-resources (including land resources) [22]. NECP's planned measures related to animal husbandry are to improve the manure management system for more efficient use of fertilizers, which is essential regarding both the plant yield and the environmental aspect;

to implement manure fermentation biogas reactors, which have the potential to reduce GHG emissions to a minimum in large farms, ensuring efficient manure management and production of renewable energy and valuable fertilizer for crops; to improve animal feeding—various methods are known and used around the world for determining the digestibility of fodder, as well as for determining and analyzing the amount of gases released by animals. Balanced and appropriate feed affects the rate of N release from manure, which has a positive effect on the reduction of N_2O emissions. Meanwhile, improving feed quality increases feed digestibility and reduces CH_4 emissions. Thoughtful, sustainable management would improve the rural population and the well-being of the inhabitants; in addition, the fertility of the land would not be reduced, the yield of crops would be increased, and the demand for energy from external resources would be reduced. It would not only reduce the impact on the environment, but also promote the competitiveness of local companies in the market by reducing expenses. This produces products with higher added value, making full use of all available resources. However, unprofessionally adopted policies that focus only on specific agricultural sub-sectors or groups of companies may not only prevent these goals, but also even delay them. It should be taken into account that agriculture is a very complex system in which simple saving measures and knowledge are not enough, because various innovations and technologies are needed in order to achieve these savings and productivity [23].

Although the planned measures are theoretically very promising, there is a huge resistance among farmers, where the prevailing concern is about the inequality and destruction of business in the agricultural sector, and the inability to compete. Due to the complicated structure of the sector, it tends to be very difficult or even impossible to determine the real obstacles and mistakes that delay the progress of sustainable farming. Therefore, this research aims to create a system dynamics model using Latvian dairy farming as a case study, which was chosen due to the existing dairy crisis in Latvia, evident by the low profitability indicators of animal husbandry [1]. It would not only provide an insight into the system's structure but also identify the system's weak links and allow for the development of recommendations.

1.1. Specifics of Dairy Farming

In animal husbandry, thermoregulation—heating, conditioning, lighting, and ventilation—is particularly important for animals kept indoors [24]. The quality of air, food, and water has the greatest impact directly on the health of animals, and therefore also on productivity, which is the most important indicator in animal husbandry [25].

Today, ranchers are increasingly using robots and algorithms in production to optimize their farm management decisions [26]. The development of technology creates a new automation system that provides smarter and more flexible work opportunities in animal husbandry [27]. These technologies provide livestock farmers with data-based insight into economic activity, which allows them to provide the necessary animal care and increase productivity, and provides them an opportunity to manage the farm more easily.

One of the biggest consumers of electricity, next to lighting, is ventilation, which often accounts for at least a fifth of the barn's maintenance costs [28], so that harmful gases such as ammonia and carbon dioxide do not exceed their critical permissible concentrations [29]. Some solutions to increase efficiency is modern building construction or innovations such as green roofs and walls to reduce indoor temperatures [27,30]. The main goal is to successfully combine mechanical ventilation and thermal insulation with natural alternatives, and such engineering solutions help to reduce energy by up to 50% [28], increasing milk productivity by at least 10–15% [31]. The most important aspect is to pay attention to thermoregulation because it will result in higher animal productivity; if dairy cows suffer from overheating during summer for about 6–15 h a day, it can result in a loss of 3.5 L of milk per day due to heat stress. Often, if all resource saving and energy efficiency measures have been taken, it is important to start thinking directly about the possibilities of installing renewable energy sources on the farm.

Development has also taken place in feeding animals. Computer programs have been developed that cover each stage of feeding: feed preparation, mixing and dosing, and feed distribution. They make it easier to plan the rations needed by the animal and give the ability to supplement the feed with fatty substances. Efficient use of feed can reduce methane gas emissions as well as give the ability to obtain the biggest yield. Furthermore, a sensor has been created that reads the movement of the animal's jaw to determine whether it digests the food completely.

One of the biggest threats in animal farming is disease, as it can spread very quickly between animals. Sickness of an animal has an economic impact on the farm, so it is important to detect the disease in its first days. Doing so reduces the cost of treatment, reduces the mortality rate, and improves production efficiency. It is possible to determine the state of health of animals by their behavior, body condition, and food intake, so companies have created programs based on the acquisition and analysis of data parameters. To obtain data from the animal, sensors are installed on it—the task of which is to collect data about the animal's condition and pass it on to analysis points [32].

1.2. Case Study of a Dairy Farm in Latvia

In Latvia, a significant part of the population lives in rural areas, which account for approximately 84% of the total area of Latvia [33]. Although field crops are responsible for more than half of agricultural emissions in Latvia, other agricultural sectors such as vegetable growing and animal husbandry—which have the lowest profitability—should not be forgotten, especially because animal husbandry is responsible for the remaining agricultural emissions, which amount to about 45% [1].

Although the farming practices of Latvian farmers can be assessed as positive not only because of the high quality products, but also because of productivity, the energy efficiency trends of the agricultural sector point to necessary improvements [34]. This is because energy efficiency has not reached the EU average over the last 8 years [32]. Furthermore, Latvia's indicators show much larger fluctuation both in the turnover of the produced products and in the energy efficiency of the agricultural sector [32].

Sub-sectors such as cereal and berry farming has been expanding in Latvia, while other sub-sectors are experiencing rather slow development or stagnating [35]. The total number of dairy farms in 2021 has decreased by 10% compared to 2020, and the total number of dairy cows has decreased by 3%, bringing the number of registered dairy cows to 131,207 [35,36]; the density of farm animals in Latvia is one of the lowest in Europe [37]. The production of milk has almost reached the EU's average milk yield, which is an important indicator of livestock welfare [38]. Additionally, the value of primary production per hectare of agricultural land in Latvia is one of the lowest in the EU, despite good climatic conditions and available water resources [39].

The system dynamics model was created based on the operating principles and data of one of the largest and most modern agricultural enterprises. Its main product is milk. There are about 470 dairy cows, and the average milk yield is 10,184 kg per cow per year, while the total milk production is 4736 tons per year. In total, there are three barns in the dairy complex where all the necessary animal welfare regulations and environmental requirements are observed. To execute the construction of cowsheds, the owner has implemented several projects of the European Agricultural Fund for Rural Development, which has enabled the introduction of innovations in the farm. This therefore increases the efficiency of farming, as well as provides the most suitable conditions for all ages of the livestock. Several projects were implemented, but the most important of them were:

- Construction of the new barn, in 2012, which cost EUR 2,641,915 with a payback time of 10 years,
- Construction of liquid manure storage in 2015, which cost 135,435 EUR with a payback time of 8 years,
- Construction of a new livestock shed in 2020, which cost EUR 1,864,564 with a payback time of 9 years,

- Purchase of a Siloking feed mixer/distributor in 2020, which cost 190,000 EUR with a payback time of 5 years.

Based on the operating principles of the farm, it can be safely stated that this company can serve as a positive benchmark for the Green Deal goals of the future.

2. Methodology

To obtain all the necessary information, a literature analysis was carried out, in which scientific articles mainly from SCOPUS, ScienceDirect databases, Google, Google Scholar, and statistics and policy documents like European Commission reports and Latvia's national plans, reports and strategies were analyzed. A combination of the following search requirements were used in the process of finding relevant information and articles: "Agriculture", "Latvia", "Europe", "Climate neutral", "Sustainable", "Carbon farming", "Green Deal", "Greenhouse gas", "Renewable", "Strategy", "Energy", "Production", "Efficiency", "National Energy and Climate plan", "Guidelines", "Economic", "Technical", "Technology", "Livestock", "Dairy farming", "Manure", "Production", "Policy", "Innovation", "Feed", "Quality", "Investment", "Thermoregulation", "Feed", "Yield", "Improvement", "Management", etc. Priority was given to the most recent articles and papers of relevance, scientific articles published in peer-reviewed journals in English. Then, one of the biggest and most modern dairy farms in Latvia was surveyed, which has already implemented several innovations for precise management, livestock welfare, modern technologies, and energy efficiency measures, while achieving a yield that significantly exceeds the average annual milking yield of a cow in Latvia and Europe. The farm owner was asked questions such as: Opinion on the Common Agricultural Policy, Carbon Farming and Support Mechanisms; Information about the company's specifics, boundaries, affiliated companies, their cooperation, the importance of cooperatives, the impact of innovations on the company's energy consumption, and the effectiveness of welfare implementation in relation to milking yield; the point of view of industry professionals on the biggest obstacles, as well as the experience of overcoming them; History of the company, its development, etc. These questions were mainly used to expand the research not only with the theoretical knowledge, but also with field professional knowledge who practically work in this field daily, while later connecting practical and theoretical knowledge by making calculations with data obtained from a real company to be able to draw the most objective conclusions and avoid any blind spots. Data were obtained from this farm and processed, such as data on energy consumption and milk yields by years, the introduced innovations and their specifics, the amount of manure produced and its processing, the amount of feed consumed, changes in number of cows and other related data; then, calculations were made. Subsequently, a system dynamics model using Latvia as a case study was made, which would not only provide an insight into the system's structure, but also identify the system's weak links and allow for the development of recommendations. The flow chart of the research development is shown in Figure 1.

The Stella Architect modeling tool was used to create a simulation model to present in a simplified mathematical way an agricultural sub sector—dairy farming. It was chosen because it not only shows the structure visually, but also includes numbers, equations, and mutual interactions of various influences. It includes economic, environmental, and technological aspects. To create a transparent insight into the structure of the dairy farm linked to the research objectives and focus, a simplified scheme was created (Figure 2).

The main schemes were shown in a simplified way and included both thermoregulation and the impact of feed quality not only on yield, but also on animal health, which in turn affects mortality, expenses, product price, and thus competitiveness. The impact of support mechanisms and the amount of sold volume were also considered, which affects savings, and in turn later allows or prevents investments in new, modern technologies that would reduce expenses and increase energy efficiency, yield, and total income. Manure processing is also included as an integral part of animal husbandry. The impact of these processes on the generated emissions is also indicated, and the investments required to reduce them are included.

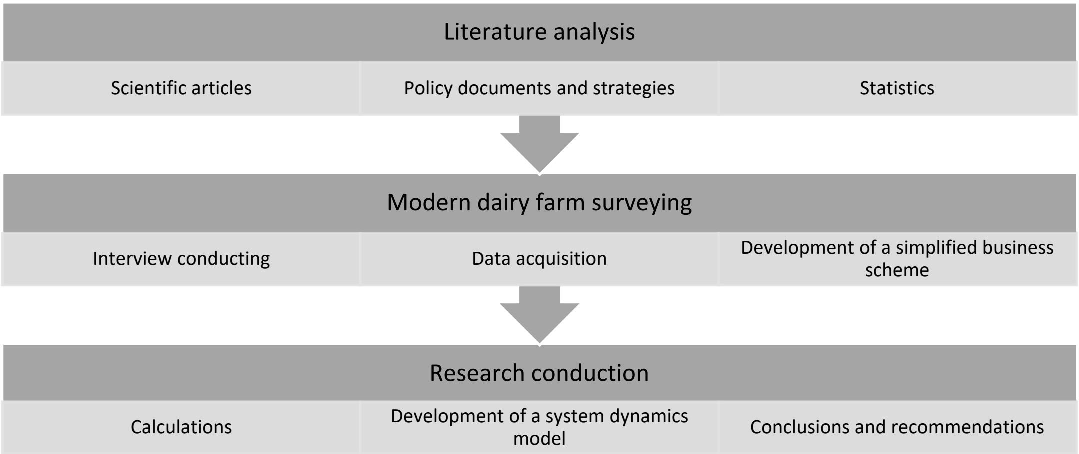

Figure 1. Flow chart of the research development.

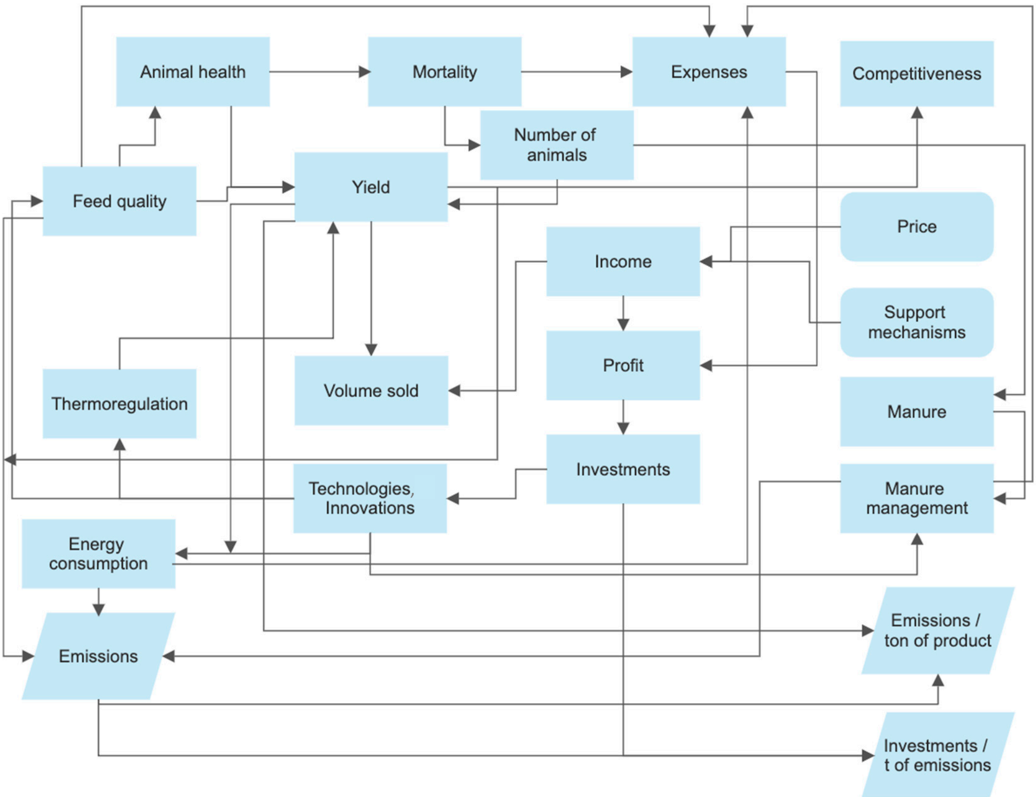

Figure 2. Simplified operation scheme of the dairy farm.

Model data input comes from two sources—literature analysis and data obtained from the specific company's survey. Data such as the number of cows, electricity and heat consumption, investments in various technologies and modernization, and milk yield were used for the case study.

The purpose of the model is to create the operation model of the dairy farm, which reflects the importance of investment implementation both in an economic and environmental context, where it is possible to observe the amount of emission reduction. It is possible to predict the importance of the implementation of investments and changes in emissions considering several interrelated influencing factors in the dairy farm model.

3. Results and Discussion

To identify the main drivers and weak links, it was necessary to model the importance of investment implementation and the change in emissions. In general, the model was divided into four sectors:

- Dairy cows;
- Investment in dairy farming;
- Economic factors;
- Emissions.

For the construction of the base model to be as close as possible to the real-life situation, it is necessary to look at several sectors in more detail so that the model is not based on assumptions, but on real data. One of the sectors that needs to be further divided into subsectors is investments in the improvements of dairy farming, where it is also necessary to consider separately the investments in the improvements of feed quality, thermoregulation, and manure management. Another sector is the economic factors, where it is necessary to study in more detail both how the savings are generated, which is a key factor needed to make the investment, and the cost of capital, which determines the total one-time costs needed to cover, for example, the construction of a new barn.

Each sector was modelled so it could be used for each emission scenario. Once the boundaries of the model study were defined, it was determined that the emissions generated would be viewed in two ways:

- Generated emissions, which will be measured in kt CO_2eq. year,
- Generated emissions per product, which will be measured in kt CO_2eq. to the annual production volume.

It was further determined that the change in emissions in the model would be determined for three scenarios:

1. The dairy farmer does not invest in any of the dairy farm performance improvement measures.
2. The dairy farmer invests only in improving manure management.
3. The dairy farmer invests in all farm improvement measures.

The scenarios were created since dairy farmers have more pressure from the state to invest in manure management than in feed quality and thermoregulation. From the first two scenarios, changes in emissions were observed, while in the third one, changes in emissions to produced production will be observed. It should be mentioned that although the model structure is created for the third scenario, it has the possibility to disable some parameter behaviour, thus creating some other scenario.

So that the data obtained by the model could be compared with the real-life situation and conclusions could be drawn, it was chosen to simulate the model in the period from 2012 to 2022. All data used in the model are obtained from dairy data, adopted considering the opinion of sector experts and literature analysis.

3.1. Dairy Cows

Dairy cows are the most important element in a dairy farm, as the obtained raw milk is the main product that brings profit to the company. Dairy cows are mostly at least two years old and have reached their first lactation. The cow sector in the model consists of two main stocks: dairy cows and sick cows (Figure 3).

Dairy cow stock has both outgoing and incoming flow. To increase the number of cows, the owner buys new dairy cows or grows heifers. If a cow's milk production drops, it is sold. Sick cows are treated, but when the treatment is unsuccessful and requires a lot of resources that would affect not only the costs, but also the yield, they are usually sent to the slaughterhouse or die naturally. Livestock health is particularly affected by the availability of high-quality feed, living conditions, and thermoregulation.

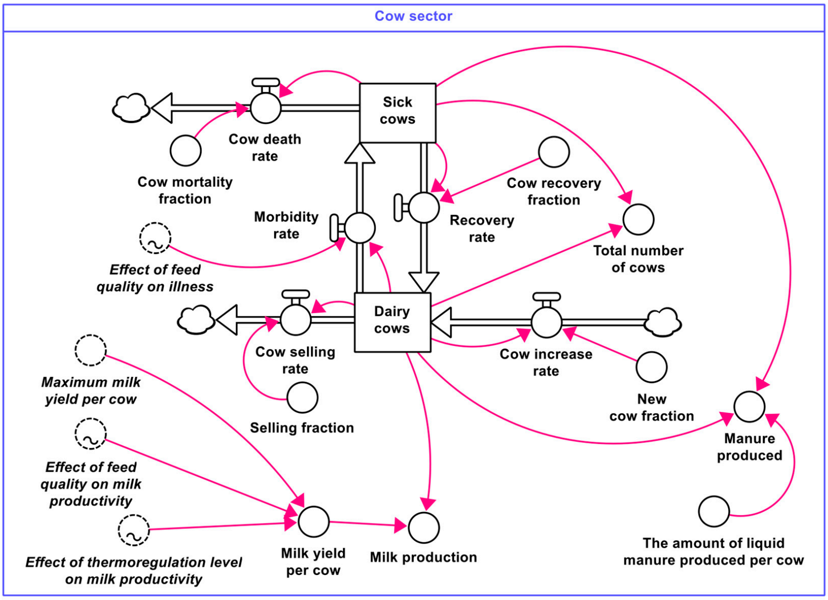

Figure 3. Structure of the cow model.

The incoming flow of the stock of dairy cows was determined considering the maximum number of beds for cows in the barn. But the outflow of the stock "sales" is determined by multiplying the sales ratio by the number of milking cows.

A similar principle applies to the cure and mortality flows of the sick cow stock, but the inflow of sick cows is affected by the level of feed quality. The effect of feed quality on morbidity is derived from a non-linear relationship in which the feed quality rating is used as an argument. The effect on morbidity ranges from 0 to 1.

Cows also produce manure from their digestive system. Manure can be divided into liquid and litter (solid). Litter manure is cow excrement with/without litter and fodder remains, and liquid manure—with urine and/or water admixture. The total amount of manure produced was calculated as tons/year.

The quantity of milk produced and sold [ton] depends on the number of cows and the average yield of one cow.

In general, milk yield per cow is influenced by several parameters, including the effect of thermoregulation level and feed quality on milk yield. Both the effect of feed quality and the effect of thermoregulation on hunger are characterized by a non-linear relationship that varies in the range from approximately 0 to 1, in which the rating of feed quality or thermoregulation level is used as an argument. In the model, the average milk yield at the beginning of 2012 is taken from the data of the reviewed dairy farm, to then be able to compare how investing in thermoregulation and feed quality improvement technologies increases milk yield.

The necessary data were obtained from the dairy farm, available statistical data, and scientific literature analysis. System dynamics model parameters for the cow sector can be seen in Table 1.

Table 1. System dynamics model parameters for the cow sector.

Parameter	Unit of Measure
Mortality rate	Dimensionless
Increase in the number of cows ratio	Dimensionless
Cow sales ratio	Dimensionless
Cow cure ratio	Dimensionless
The amount of liquid manure produced per cow	tons/year
The amount of litter manure produced per cow	tons/year
Number of milking cows	Number of cows
Maximum number of cow places in the barn	Number of cows
Maximum milk yield per cow	tons/cow/year

3.2. Emissions

The emission sector in the model represents emissions from the company, as well as emissions per unit of production. It is necessary to calculate the emissions to be able to evaluate the progress towards climate neutrality. In dairy farming, the main GHG emissions come from intestinal fermentation and manure management. Although in the documentation, the calculation of emissions from fuel consumption, electricity, and heat production is below the energy and transport sector, it is important to include it. In the model, the emission sector has two main stocks and two main flows (Figure 4).

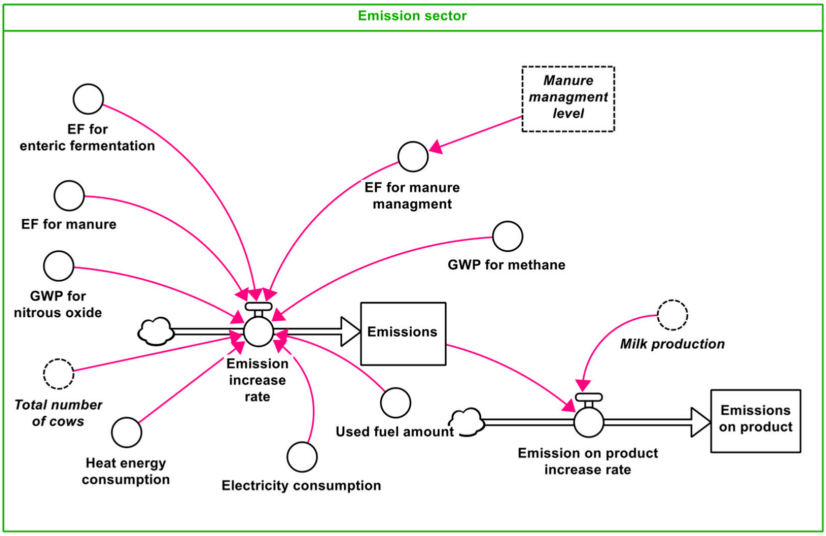

Figure 4. Structure of the emission model.

Methane emissions from intestinal fermentation processes, GHG emissions generated to produce the consumed electricity and heat energy, as well as GHG emissions generated due to fuel consumption were calculated. Manure emissions were also calculated; however, several parameters must be considered when calculating manure. Organic matter and water make up most of the composition of manure. Manure emits both methane and nitrogen oxide emissions. How much methane is released from manure depends on its oxygenation, water content, pH level, and feed digestibility [40]. How much nitrous oxide is produced depends on climate, pH, and manure management. To be able to perform a unified accounting of emissions, it is necessary to switch to CO_2eq. In general, both dairy farm data and predetermined constants were taken for the calculation (Table 2).

Table 2. Input data for the emission sector in the model.

Parameter	Unit of Measure
Heat energy consumption	MWh/year
Fuel consumption	litre/year
Diesel fuel combustion	MWh/ton
Electricity consumption	kWh/year
Global warming potential of CH_4	Dimensionless
Global warming potential of CO_2	Dimensionless

Electricity and heat consumption are currently represented as constant values in the model. It is also necessary to calculate the emitted emissions per production quantity, which can be calculated by dividing the generated emissions by the produced production quantity.

3.3. Economic Factors

It is important to look into the economic sector as it is one of the determinants of investment and savings, providing a safety net and a sense of security for a farmer that the company will have a better chance of getting out of financial difficulties after taking risks on new investments [41]. In dairy farming, the biggest expenses come from electricity consumption charges, dairy cow treatment costs, and capital costs, while income comes from milk production and sales, where they are affected by the amount of milk sold, which depends on the yield obtained from the cow. Cow and milk prices determined by the cooperative, additional income also comes from the sale of culled cows, where the price per cow depends on the market. Income is exactly the factor that contributes to the accumulation of profit, because even if the expenses are very high, if there is a large income, the accumulated profit will also be within the norm. A feedback loop is also created from the amount of accumulated profit because investment decisions are made from the amount of accumulated profit and own available financing. If a decision is made to make investments, then the reduction in retained earnings is determined by the channeling of funding to investments and the self-financed part (Figure 5).

The capital cost sector consists of one main stock—capital cost, the increase of which is determined by making capital investments, which is affected by the discount rate, bank loan, and the loan repayment period, while the reduction of the stock is affected by the repayment period, the capital investor, and the capital costs themselves. A dairy company needs to take a loan from a bank to cover the costs needed to make improvements to the farm which are not compensated for by the support offered by the state.

For the sector to work in the model, it is necessary to enter data; therefore, the input data used in the savings and capital expenditure sector are summarized in Table 3.

Table 3. The input data in the savings and capital expenditure sector.

Parameter	Unit of Measure
Heat energy costs	EUR/MWh
Fuel costs	EUR/liter
Cow cure costs	EUR/year
Cow costs	EUR/cow
Voluntary related support for milking cows	EUR/cow
Share of own financing	Dimensionless
Intensity of support measures	Dimensionless

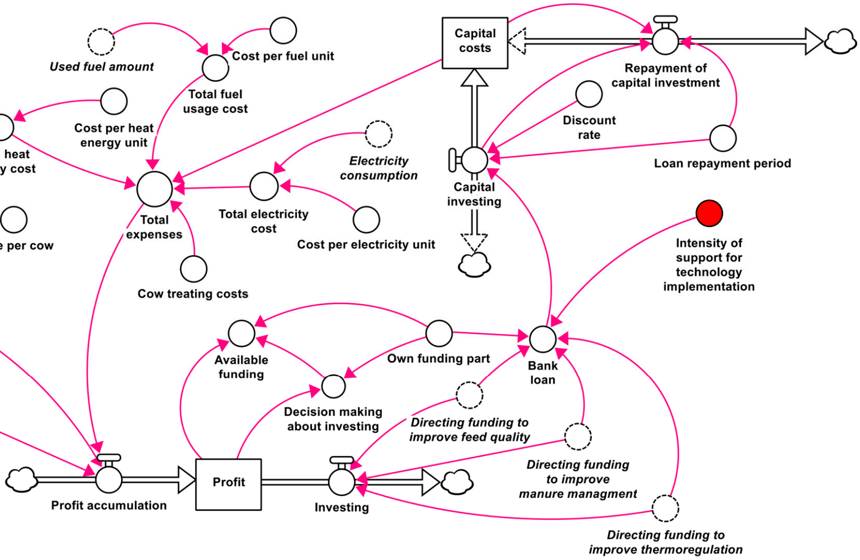

Figure 5. Structure of the economic model.

3.4. Investment in Dairy Farming

To manage dairy cow manure, it is possible to use different management methods. Each type of manure management in the model is evaluated in points, where they determine the level of management on the farm. Each type of management has its own determined emission factor (Table 4).

Table 4. Manure management method, level and factor.

Management Method	Management Level, Points	Emission Factor [42]
Deep bedding + mixing	1	0.07
Solid storage	2	0.02
Liquid systems	3	0.0005
Anaerobic lagoon	4	0.001
Biogas production	5	0.0006
Biomethane production	6	0

The model considers the time required to implement improvements at the management level (Figure 6). The improvement of the level is also influenced by the ratio between the funding diverted for improvement and the investment required to improve manure management by one point. The necessary investment for improvement per cow is determined by the necessary investment for raising the quality indicator by one point, the difference between the maximum and management level in the farm, as well as the available support measures. To determine whether it is worth investing in the improvement of manure management, the time implementation of improvement measures is determined by whether the improvement of manure management contributes to an increase in income. If the manure is used to produce biogas, it is possible for the dairy farmer to receive payment for the manure sold to the biogas plant, unless the farmer himself has invested in the biogas plant.

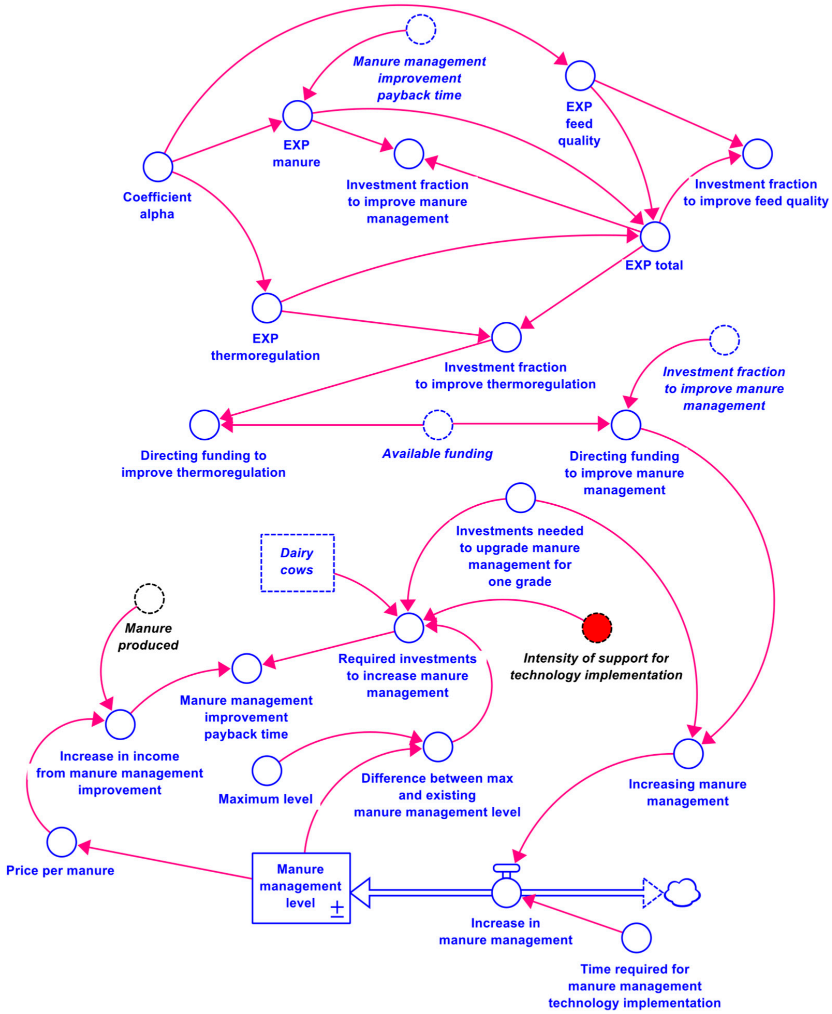

Figure 6. Structure of the investment in manure management model.

Feed quality is included because it affects milk yield, the health of cows, generated emissions, and the farm's profit (Figure 7). The most important indicator by which feed quality is determined is feed digestibility (%). In the model, feed quality is measured on a scale of 1 to 10, where 1 is the worst feed quality indicator and 10 is the best. However, to achieve high feed quality, it is necessary to invest in technologies to achieve the set goal. The effect of feed quality on milk yield varies between approximately 0.1 and 1 and is derived from a non-linear relationship using the feed quality score as the argument. The model also examines how income could increase as feed quality increases to determine the payback period. The increase in feed quality is affected by the time it takes to introduce a new technology, as well as the ratio between the funding diverted to improve quality and the investment needed to improve quality by one point. The necessary investment for improvement per cow is determined by the necessary investment for raising the quality indicator by one point, the difference between the maximum and the existing level of feed quality on the farm, as well as the available support measures.

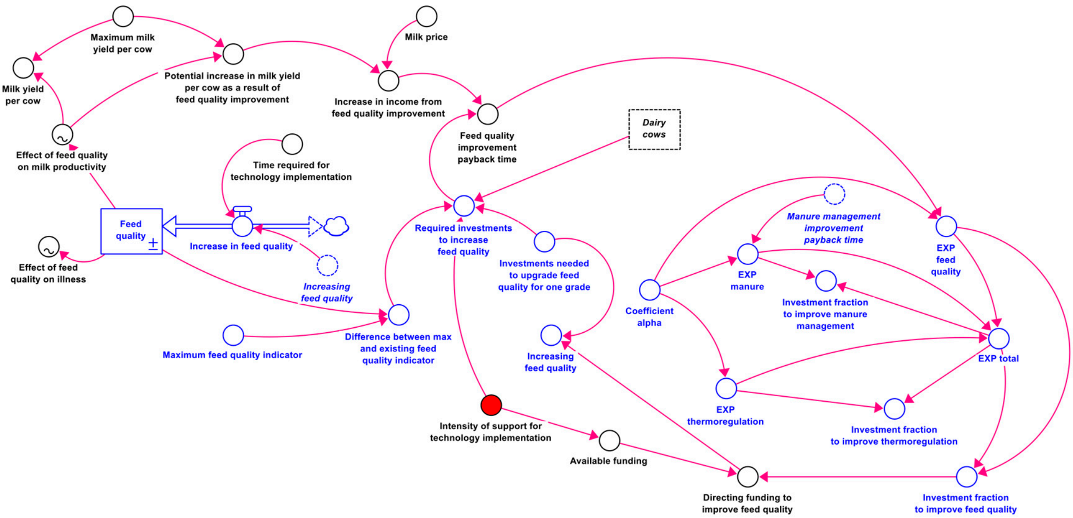

Figure 7. Structure of the investment in feeding quality model.

It is crucial to make improvements in thermoregulation to improve the well-being of livestock, which would also affect the milk yield significantly and reduce diseases. In the model, the level of thermoregulation is evaluated on a scale from 1 to 10, where 1 is the worst thermoregulation, and 10 is the best. The effect of thermoregulatory level on yield varies between 0.1 and 1, and is derived from a non-linear relationship using the thermoregulatory level score as an argument. The model also explores how earnings could increase if the level of thermoregulation is increased to determine the payback period (Figure 8).

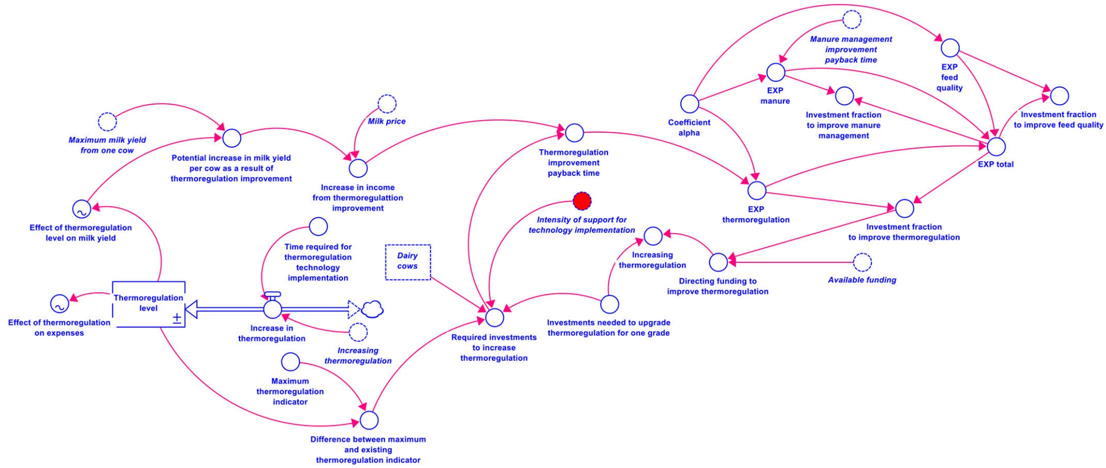

Figure 8. Structure of the investment in the thermoregulation model.

The increase in the quality of thermoregulation is also affected by the time it takes to implement a new technology, as well as the ratio between the funding diverted to improve thermoregulation and the investment to improve by one point. The necessary investment for improvement per cow is determined by the necessary investment for improving thermoregulation by one point, the difference between the maximum and existing levels in the farm, as well as the available support measures. For the model to function, the data reflected in Table 5 were entered.

Table 5. Input data for the technology development.

Parameter	Unit of Measure
Time to implement	Years
Manure price	EUR/ton
Max level	Points
Initial level	Points
Investments for technology improvement for one point	Points

3.5. Results from the Case Study and the System Dynamics Model

By the calculations based on the data of the dairy company, it was found that it is possible to achieve several improvements by investing:

By building a new barn, the company:

- reduced electricity consumption by 7000 kWh/year, which is a 46% reduction,
- increased milk yield from one cow by 2129 kg/cow/year, which is a 25% improvement compared to the year of making the investment,
- increased milk yield from one cow by 3987 kg/cow/year, which is a 42% improvement, compared to the 10-year average milk yield before the investments.

By investing in feed feeding technologies, the company increased milk yield by 174 kg/cow/year, which is a 2% improvement compared to the year of making the investment.

From the system dynamics model, it was determined that the generation of emissions in both the first and second scenario is characterized by a linear curve (Figure 9a). The number of generated emissions increases every year as the number of cows increases, which thus increases the number of emissions generated from intestinal fermentation processes. However, because of the introduction of innovations, it is possible to observe a reduction in emissions, as a higher level of manure management reduces emissions from manure.

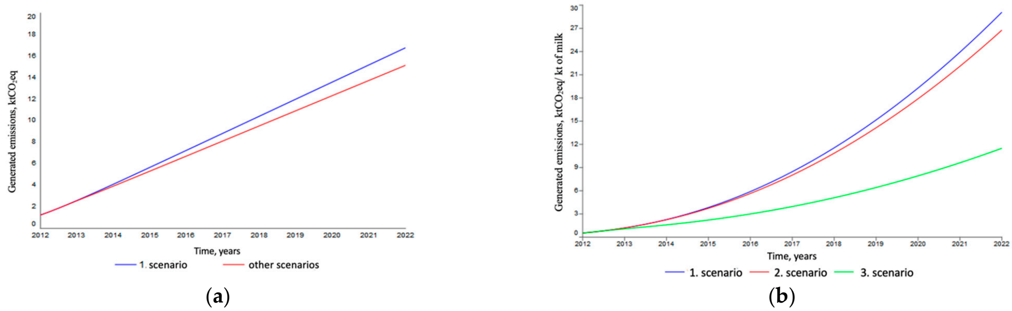

Figure 9. (**a**) The total amount of emissions produced in several scenarios; (**b**) The total amount of emissions generated per the amount of output produced in several scenarios.

When comparing the emissions created in these scenarios, 2017 and 2022 were taken as reference points, and it was determined that with the help of the 2nd scenario, compared to the first scenario, emissions are reduced by 0.1% in 2017 and by 10% in 2022.

Then, the generated emissions per produced quantity, which is the most essential and objective indicator in agriculture, was examined. Figure 9b shows the emissions per produced amount of production, which is measured in kt CO_2eq/kt of milk produced. In general, it can be observed that the 1st scenario also produces the highest emissions for the production, while the 2nd scenario produces less emissions than the 1st scenario only from 2015, but in the 3rd scenario, significant changes can be observed compared to the other two scenarios.

When comparing the generated emissions between the scenarios, 2022 was taken as a reference point. It was found that by implementing the second scenario (when investments only in manure management technology development are made), compared to the first scenario (when no improvements are made), it is possible to achieve a reduction in emissions by 8% (2.32 ktCO_2eq/kt of milk) in 2022.

When comparing the generated emissions between the second scenario (where improvements only in manure management are made) and third scenario (where improvements in manure management, thermoregulation and feed improvement are made), it was found that by implementing the third scenario, it is possible to achieve a reduction in emissions by 57% (15.28 CO_2eq/kt of milk) in 2022.

When comparing the generated emissions between the first scenario (where no improvements are made) and third scenario (where improvements in manure management, thermoregulation and feed improvement are made), it was found that by implementing the third scenario, it is possible to achieve a reduction in emissions by 60% (17.59 CO_2eq/kt of milk) in 2022.

The increase in the number of cows occurs up to and including 2016, but remains constant thereafter. Comparing the year 2013 with the year 2022, it can be determined that the number of cows has increased by 23%.

The initial milk yield per cow was 6.377 tons/cow, which remains unchanged in the first and second scenario, but in the third scenario, it is possible to observe an increase in milk yield in the maximum average milk yield per cow, which is 15.870 t/cow per year. Comparing the first year of the third scenario with the last one, it is possible to observe an increase of 69% (5261.45 t more), but comparing the third and first scenarios of 2022, it can be concluded that by investing in the improvement of the farm, it is possible to achieve a 60% higher amount of production, which is 4550.99 t more (Figure 10).

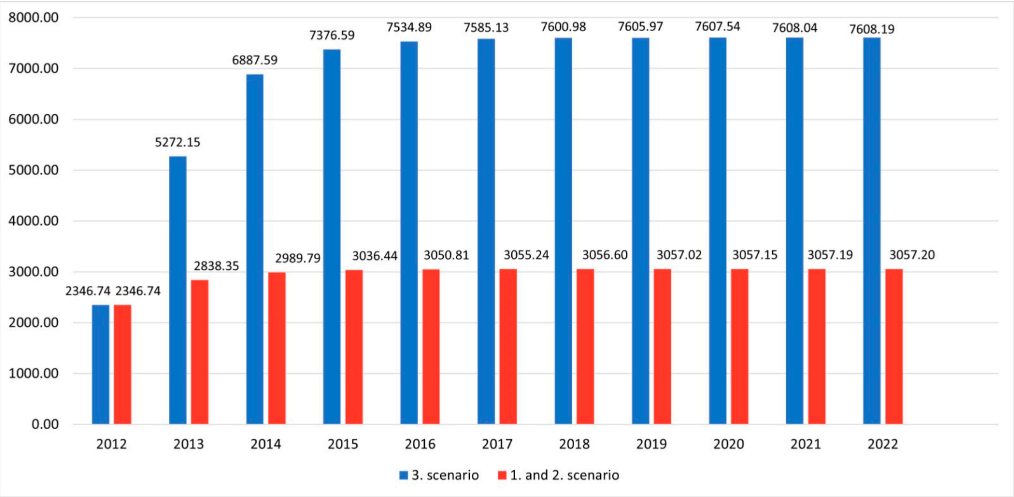

Figure 10. Milk production in the first, second, and third scenarios.

4. Conclusions

The strategic documents emphasize manure management and improvement of feed quality, but an important missing element is visible—a section on improving the thermoregulation of animals. All these elements (manure management, feed quality, and thermoregulation) are an integral part that must work in one system, because their improvement significantly improves productivity, reduces energy consumption, improves resource efficiency, and reduces direct and indirect emissions not only in agriculture, but also in the energy and transport sectors.

It should be noted that the larger the volume of production, the lower the number of emissions produced per unit of production. However, in agriculture, it is possible to achieve it mainly through investments in new, modern technologies, because an ill-considered economy of energy or resources can result in yield losses, which would not be a sustainable solution at the company or at the state level. Agriculture cannot focus only on energy efficiency and greenhouse gas emission reduction without consideration of aspects such as the impact of the activities on yield, technology, free available funds, market stability, state support, and others. It is important to look at ways to increase productivity while introducing energy-efficient and resource-efficient methods—a thoughtful management model. Only that way would it be possible to achieve sustainability from both an environmental point, and also from an economic point.

However, such technologies require investments, which are directly affected by the company's income and savings, and in turn are affected by the volume sold and the price of the product in the market, support mechanisms, existing technological level, and efficiency. To ensure the sale of the product on the market at a sufficiently high price for the company to develop innovation, it is important to develop a national policy that guarantees sales of the local producer's products. This is very important, because if there is more support and protection for agricultural enterprises in competing countries, not only will the price be competitive, but the safety of selling the products on the market will also fall. Ill-considered local policy fail to promote opportunities for local producers' innovation development comparing to competing countries' companies. This is especially critical now, when adapting to climate change and trying to fulfill the Green Deal goals; failing to develop sustainable policies risks destroying the local market's ability to compete and exist.

The created system dynamics model allows us both to understand and to model possible scenarios; to calculate not only the impact of a given company or sector on the environment by calculating the generated emissions per unit of production, but also to calculate the investments required to reduce 1 kt of CO_2eq generated in the company. Such a model makes it possible to make sustainable decisions not only at the level of the company, but also at the level of state policy, to simultaneously promote environmental goals, economic growth, and the development of the national economy.

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