GFarm

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Table of Contents

1.Best practices assessment of the currently available best practices and initiatives 7
1.1 GHG Reduction Practices in CAP and Latest Public Sector Initiatives 7
1.2 Information on EC's 'Carbon Farming' 9
1.3 'Carbon' Farming and Accounting Practices and Trends in Forestry 10
1.4 Carbon Farming R&I activities in EU and progress in Lithuania 18
1.5 Climate Change Management Policy: Objectives and Challenges 25
1.6 Policy Relevance of Carbon Farming in Lithuania 26
1.7 Overview of Successful Projects and Examples from Other Countries 27
2. Best research practices assessment for GHG emission estimation and monitoring in agriculture 28
2.1 GHG emissions from transport in agriculture 28
2.2 Soil tillage impact on GHG emissions 30
2.3 Other technological operations (fertilizer, spraying) impact on GHG emissions 33
2.4 GHG emission in animal husbandry 38
2.5 Experiences of other countries using technologies and instruments reducing GHG and increasing CO_2 absorption 40
2.6 Review and evaluation of existing or developing platforms or calculators 41
2.7 Overview of applied technological solutions for monitoring GHG emissions in AFOLU sector 46
2.8 International practices applied in other countries of GHG platforms or calculators 48
3. Best practices assessment in carbon monitoring and sequestration 50
3.1 National efforts of carbon sequestration in LULUCF sector 50
3.2 Carbon certification 53
3.3 Technologies used in MRV 57

List of Tables

Table 1. The implementation of eco-schemes within the CAP Strategic Plan in 2023
Table 2. carbon removal methodologies in forestry used by EU countries
Table 3. Ongoing EU projects related to common themes
Table 4. Successful EU projects and examples
Table 5. Values used for Tier 1 CO_2 calculations
Table 6. Carbon dioxide equivalent values of agricultural inputs
Table 7. GHG emissions in different winter wheat and winter oilseed rape cultivation treatments
Table 8. Overview of 44 environmental assessment calculators for agricultural products

List of Figures

Figure 1. Climate change mitigation potential in 2030 (PgCO2e yr-1)
Figure 2. Voluntary carbon credits share according to sources in 2023
Figure 3. Forest VCC issuance according to different forest measures
Figure 4. VCC price forecast, tCO_2e (USD)
Figure 5. CSRD compliance timeline
Figure 6. Annual emissions from companies with SBTi commitments and pledges vs potential supply from current projects and pipeline ($MtCO_2e$)
Figure 7. Carbon removals by North European birch (Ecobase project - Latvian case)
Figure 8. Carbon credit calculations for poplar plantations in Lithuania (tCO_2/ha)
Figure 9. Fuel consumption at different engine speed, when driving speed on stubble – 8 km/h, on gravelled road – 18 km/h
Figure 10. Dependence of engine load and fuel consumption on driving speed at transport work
Figure 11. Percentages of tractor performance indicators by the modes of ploughing process
Figure 12. Biopreparation effectiveness for reducing fuel consumption and CO_2
Figure 13. Contribution of different inputs in CO_2eq for winter wheat production
Figure 14. Impact of (i) animal manure and mineral fertilizer application rate (kg N ha-1) and (ii) manure type on (a) CO_2, (b) CH_4 and (c) N_2O emissions from agricultural soils
Figure 15. CO_2, (b) CH_4 and (c) N_2O emissions from agricultural soils affected by soil textural class
Figure 16. Influence of (i) crop duration (days) and (ii) crop type on (a) CO_2, (b) CH_4 and (c) N_2O emissions from agricultural soils
Figure 17. Effect of climate zone on (a) CO_2, (b) CH_4 and (c) N_2O emissions from agricultural soils
Figure 18. Selection process for GHG emission calculators for energy crop cultivation

Abbreviations

AFOLU *- Agriculture, Forestry, and Other Land Use*
ARR *- Afforestation and Reforestation*
CAP *- Common Agricultural Policy*
CAR *- Corrective Action Request*
CDR *- Carbon Dioxide Removal*
CFP *- Carbon Footprint*
CL *- Clarification Requests*
CRCF *- Carbon Removal Certification Framework*
CRF *- Common Reporting Format*
CSRD *- Corporate Sustainability Reporting Directive*
CT *- Conventional Tillage*
ERU *- Emission Reduction Units*
ESG *- Environmental, Social and Governance*
ETF *- Enhanced Transparency Framework*
ETS *- Emissions Trading System*
GAEC *- Good Agricultural and Environmental Conditions*
GIS *- Geographic Information System*
GHG *- Greenhouse Gas*
IFM *- Improved Forest Management*
IN *- Number of Inquiry*
IPCC *- Intergovernmental Panel on Climate Change*
LCA *– Life Cycle Assessment*
LULUCF *- Land-Use, Land-Use Change and Forestry*
MRV *- Monitoring, Reporting and Verification*
NECP *- National Energy and Climate Action Plan*
NIR *- National Inventory Report*
REDD *- Reducing Emissions from Deforestation and Forest Degradation*
SBTi *- Science Based Target Initiative*
SFDR *- Sustainable Finance Disclosure Regulation*
SMR *- Statutory Management Requirements*
SOC *- Soil Organic Carbon*
UNFCCC *- United Nations Framework Convention on Climate Change*
VCC *- Voluntary Carbon Credit*
VCS *- Verified Carbon Standard*
VVB *- Validation and Verification Bodies*
WAM *- Planned Policy Measures*
WEM *- Existing Policy Measures*

Introduction

The global approach for transitioning towards carbon farming in Agriculture, Forestry, and Other Land Use (AFOLU) sectors is a comprehensive strategy aimed at climate change by implementing carbon sequestration and reducing greenhouse gas emissions. This project approach is essential because the AFOLU sectors are both a source of carbon emissions and a potential for carbon sink. Implementing carbon farming practices can play a significant role in mitigating climate change while also offering economic, environmental, and social benefits.

This deliverable provides a roadmap for a detailed and structured analysis of the systemic approach to transitioning towards carbon farming in the AFOLU sectors, focusing on best practices, challenges, and innovative solutions to mitigate climate change through sustainable land use and agricultural practices. The previous EU roadmaps of carbon farming, emissions and sequestration are analyzed. To add, the MRV is reviewed including upcoming voluntary carbon credits market system.

Particularly, the focus of Lithuania, presenting a compelling case study on the nation's concerted efforts and activities within the carbon farming and carbon credits area. This offers understanding of the integration of carbon farming at the country's level. It could serve as a lighthouse for not only other nations joining similar environmental management, but also forming the whole EU policy. Moreover, GFarm gets into the objectives and challenges rising to climate change management policy, especially to carbon farming and the reduction of GHG emissions.

This deliverable gets into the specific contributions of transport-related emissions in agriculture, highlighting the importance of addressing these emissions in the transition to carbon farming.

It is presented the review of main nature of GHG emissions deriving from agricultural machinery. It also represents successful projects and examples from across the globe. These examples highlight and clarify effective strategies and lessons learned, essential for informing and enhancing future initiatives.

A comprehensive review of GHG emissions from various agricultural operations, including but not limited to transport, soil tillage, fertilizer application, spraying operations, and animal husbandry, is presented.

Furthermore, it is explained how different countries have used technologies and instruments to manage GHG emissions while enhancing CO2 absorption. This will support evaluating platforms or calculators and reviewing technological solutions for the monitoring of GHG emissions within the AFOLU sector among international practices.

The deliverable D2.1 forms an in-depth expertise of practices in carbon monitoring and sequestration, until nowadays. Underlining the importance of measuring carbon stocks and flows, it also highlights best practices, the role of technological solutions and international cooperation in implementing carbon sequestration efforts.

1. Best practices assessment of the currently available best practices and initiatives

1.1 GHG Reduction Practices in CAP and Latest Public Sector Initiatives

The Lithuanian Strategic Plan for Agriculture and Rural Development for 2023–2027 charts a path toward sustainable growth by aiming to enhance the sector's added value and competitiveness. A total of around EUR 3 billion is allocated for income support (covering approximately 2.8 million hectares) and will contribute to maintaining local production.

Lithuania has set a strategic target to reduce agricultural GHG emissions by 11% by 2030 relative to 2005 levels. The plan incorporates statutory management requirements (SMR) aimed at safeguarding water resources, biodiversity, feed and food safety, animal health, the safe usage of plant protection products, and ensuring animal welfare. Also, the plan underlines Good Agricultural and Environmental Conditions (GAEC) that support climate change mitigation and adaptation, water resource protection, soil preservation and improvement, as well as biodiversity and landscape conservation. These conditions are designed to create a more resilient agricultural landscape capable of enduring and adapting to environmental challenges.

A notable part of the plan involves the eco-schemes, which are a transformative initiative within the CAP. It is planned to use 25% of the direct payments budget to support eco-schemes within actions that incentivise farmers who voluntarily implement environmentally and climate-friendly practices going beyond the mandatory requirements under GAEC. Farmers can choose to participate in 10 different eco-schemes that cover all types of agricultural area (arable land, permanent crops, grassland, wetlands) and receive support for a wide range of management practices. In 2023, 54 292 applicants, representing 47% of all farmers who declared, chose to participate in these eco-schemes. The most popular eco-schemes include non-tillage practices, catch crops, crop rotation, and landscape feature maintenance, which are pivotal in reducing GHG emissions and promoting a sustainable agricultural ecosystem.

For a comprehensive understanding of the eco-schemes' scope and impact in 2023, reference the accompanying table, which details the statistics of participation and area coverage by these eco-schemes (Table 1).

Table 1. The implementation of eco-schemes within the CAP Strategic Plan in 2023. Updated 2024-02-07

Program Name	Supported Group Name	Number of Applicants	Number of Declared Fields	Declared Area, HA
Replacement of arable peatlands with grassland	Replacement of arable peatlands with grassland	402	788	1 953
Organic farming (fruit, berries, vegetables, medicinal herbs and spice plants)	Organic farming (fruit, berries, vegetables, medicinal herbs and spice plants)	576	1 763	5 345
Conversion to organic farming	Conversion to organic farming for perennial grasses	558	3 653	7 456
	Conversion to organic farming for vegetables, potatoes, berry, gardens, medicinal herbs, aromatic and spice plants	115	286	842
	Conversion to organic farming for cereals, forage cereals, cereals for seed and perennial grasses for seed	557	2 655	10 097
Establishment of grassland on eroded soil	Establishment of grassland on eroded soil	19	89	41
Extensive management of wetlands	Extensive management of wetlands	257	776	2 005
Management of natural grasslands, wetlands and habitats of species of EC interest	Natural grasslands of EC interest	229	893	2 450
	Management of wetlands of EC importance	0	0	0
Extensive management of permanent grassland by grazing livestock	Extensive management of permanent grassland by grazing livestock	1 627	7 513	22 822
Nature-friendly orchard and berry management	Nature-friendly orchard and berry management	157	522	1 081
Sustainable fruit, berries and vegetables programme (NCP)	Sustainable fruit, berries and vegetables programme (NCP)	76	349	1 496
Crop rotation	Crop rotation	4 404	84 059	571 892
Strips of permanent grassland	Strips of permanent grassland	640	1 983	3 738
Maintenance of landscape elements	Maintenance of landscape elements. Maintenance of existing landscape elements	7 359	46 316	4 790
	Maintenance of landscape elements. Establishment of new herbaceous elements	2 981	8 035	879
	Maintenance of landscape elements. Planting of new woody elements	13	26	1
Short-lived melliferous plant strips	Short-lived melliferous plant strips	595	1 644	5 349
No-tillage practices	No-tillage practices	18 024	196 017	1 171 413
Application of certified seeds	Application of certified seeds	3 968	29 260	200 870
Intermediary crops	Intermediary crops	11 735	54 286	325 791

An important share of the CAP support, around 35% of rural development funding, is allocated to farm modernisation (including farms of young farmers) and sustainable investments, such as investments in modern machinery for more sustainable fieldwork, more animal-friendly stables or renewable energy. In order to diversify financing sources, support is also used to help beneficiaries access loans on preferential terms.

1.2 Information on EC's 'Carbon Farming'

Introduction to 'Carbon Farming'

Carbon Farming initiative seeks to create direct incentives for land managers in the agriculture and forestry sectors to foster carbon capture from atmosphere, which is essential for reaching climate-neutral economy. The initiative was introduced by the European Commission with the adoption of Communication on Sustainable Carbon Cycles (COM (2021) 800) in December 2021. This document outlined i) the general model of the initiative, ii) natural carbon sequestration practices, iii) key challenges in creation of sustainable, effective, and widespread scheme, as well as iv) short- to medium-term actions to tackle these challenges. These key actions include:

- promoting carbon farming practices via targeted policy instruments and financial incentives under the Common Agricultural Policy (CAP), other EU programmes, and public national financing;
- providing standardisation of monitoring, reporting and verification (MRV) methodologies to create a clear and reliable framework for carbon farming;
- granting emission and carbon removal data at farm level and offering custom advisory services to land managers.

After extensive analysis of existing carbon certification frameworks and engagement of the expert groups, the European Commission derived a proposal for a Regulation on an EU certification of carbon removals (COM (2022) 672) in November 2022. This proposal introduced quality standards for carbon removals (credits) and general framework for certification, MRV, operation of registries for carbon removals, etc.

Quality criteria (abbreviated as QU.A.L.ITY) include Quantification (making removals accurate, consistent, and comparable), Additionality (both regulatory and financial), Long-term storage (mitigating the risk of releasing carbon before the end of monitoring period), and Sustainability (activities of carbon removals must have a neutral impact to environment or generate co-benefits to other sustainability objectives).

Compliance to quality criteria shall be ensured by several layers of regulations, starting with approved methodologies for carbon removal, certification schemes that were recognised and approved by the European Commission, public registries of certified carbon credits, and the overall supervision of carbon certification process.

MRV - measurement, reporting, and verification

Proposal for a Regulation on an EU certification of carbon removals outlines key principles of MRV. Carbon removals (credits) must comply with quality criteria and be independently verified. Compliance of the carbon removal activity and verification of carbon removals shall be carried out by independent Certification bodies that must be accredited by national accreditation authorities and appointed by Certification schemes. Certification bodies shall be competent to carry out certification and periodic re-certification audits and independent from the operators of carbon removal activities.

Certification schemes shall be responsible for selecting and training of Certification bodies, addressing non-conformity issues, and development and management of public registries of carbon removals. Certification schemes shall verify if carbon removals were independently verified, and the certification of compliance was carried out in an accurate, reliable, and cost-effective manner.

Upcoming Regulations

Proposal for a Regulation on an EU certification of carbon removals is now being discussed by the European Parliament and the Council, in line with ordinary legislative procedure. Following adoption of the Regulation, the European Commission shall approve certification methodologies for different types of carbon removal practices (to be ratified in 2024) and adopt implementing acts for regulation of certification frameworks and MRV processes, including structure, format, technical details, and process of Certification schemes, Certification bodies, and public registries. As a result, voluntary carbon removal framework shall be fully implemented by 2028.

1.3 'Carbon' Farming and Accounting Practices and Trends in Forestry

Global trends

Forest have been always perceived as perfect nature based carbon sink which is easy to understand, easy to measure and observe by carbon buyers, therefore forest based carbon credits have for a long time most favored by the markets. The absolute majority of forest related carbon credits have been associated with Reducing Emissions from Deforestation and Forest Degradation (REDD) projects, which are implemented in developing markets. Other Forest instruments that are getting their way in developed markets include ARR (afforestation and reforestation) and IFM (improved forest management.

It is estimated that overall nature based climate solutions globally in 2030 may have $PgCO_2e$ yr-1 i.e. up to 30% of global emissions mitigation potential that has to ensure <2C degree ambition (Fig. 1). Out of all nature based solutions forest are undoubtfully key climate mitigation instrument.

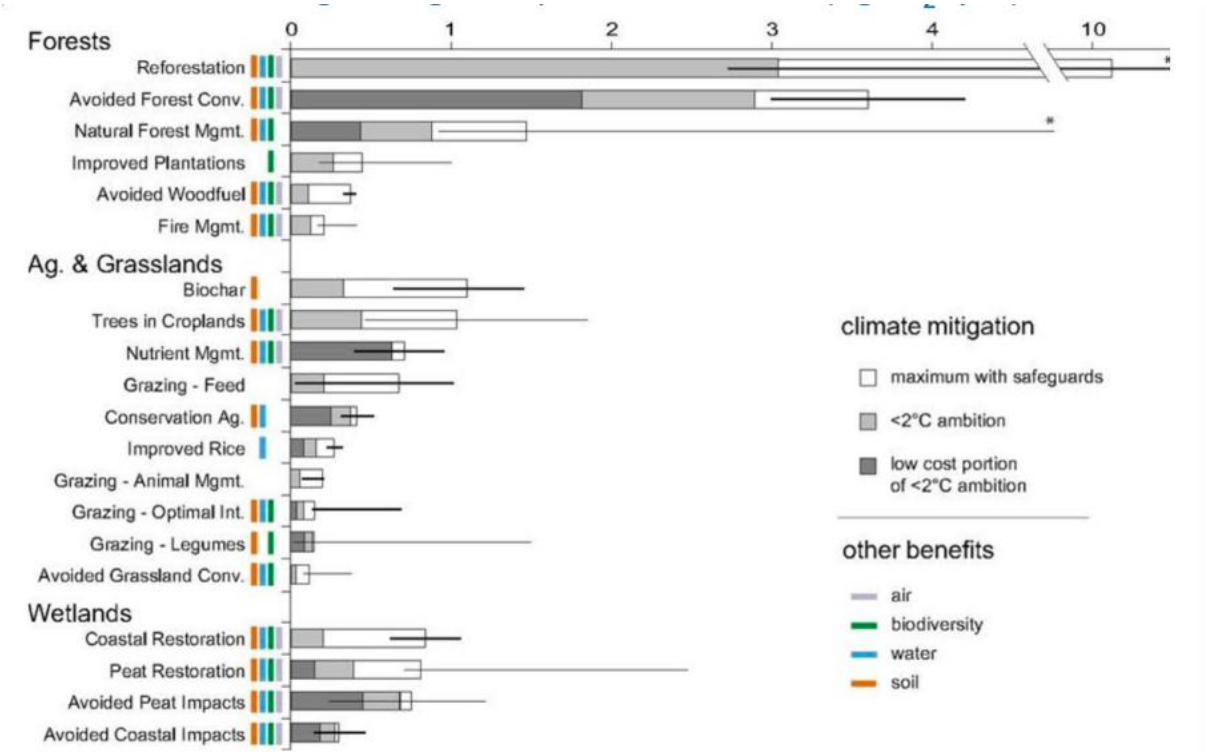

Figure 1. Climate change mitigation potential in 2030 ($PgCO_2e$ yr-1)

Voluntary carbon markets can play a pivotal role bridging the gap of funding to utilize climate change mitigation potential. Voluntary carbon market value already reached 2 billion USD in 2022 and in order to meet <2C degree climate change ambition it is expected to raise to 1 trillion USD in 2050 (Fig. 2). Besides social motivation to combat climate change, the key drivers for rapid development of voluntary

carbon markets are related to legal and voluntary disclosure obligation of businesses through CSRD, SFDR, CDR other reporting standard implementation.

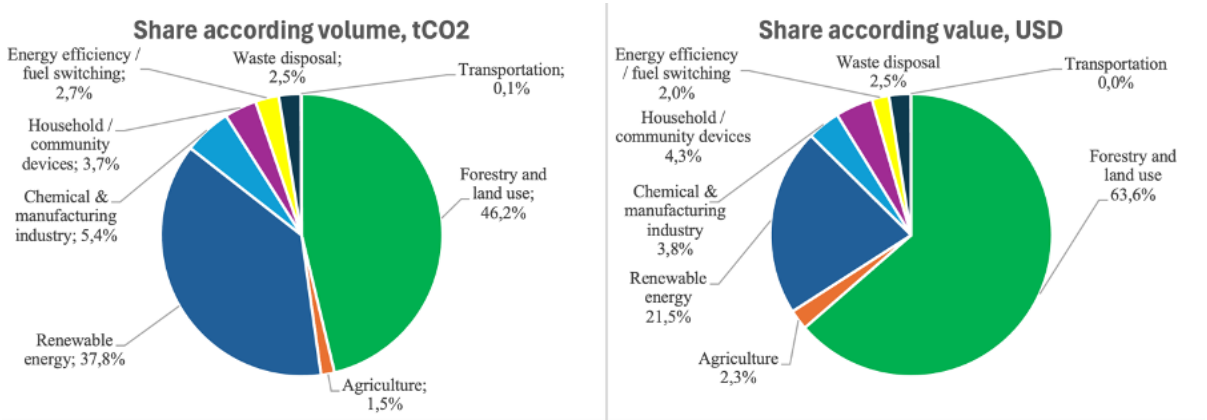

Figure 2. Voluntary carbon credits share according to sources in 2023

Forest based voluntary carbon credits in 2022 had 46,2% in global VCC volume and even higher share in the value – 63,3%, because all nature based VCC were priced the highest.
Among Forest based VCC, REDD based VCC strongly prevailed, but new tools such ARR and IFM are picking up as well. Especially strong growth is in afforestation VCCs, while improved forest management still at a low level because methodologies are still under development. As biodiversity issues are getting more attention it can be expected that conservation forestry (IFM) VCCs will be on the rise (Fig. 3).

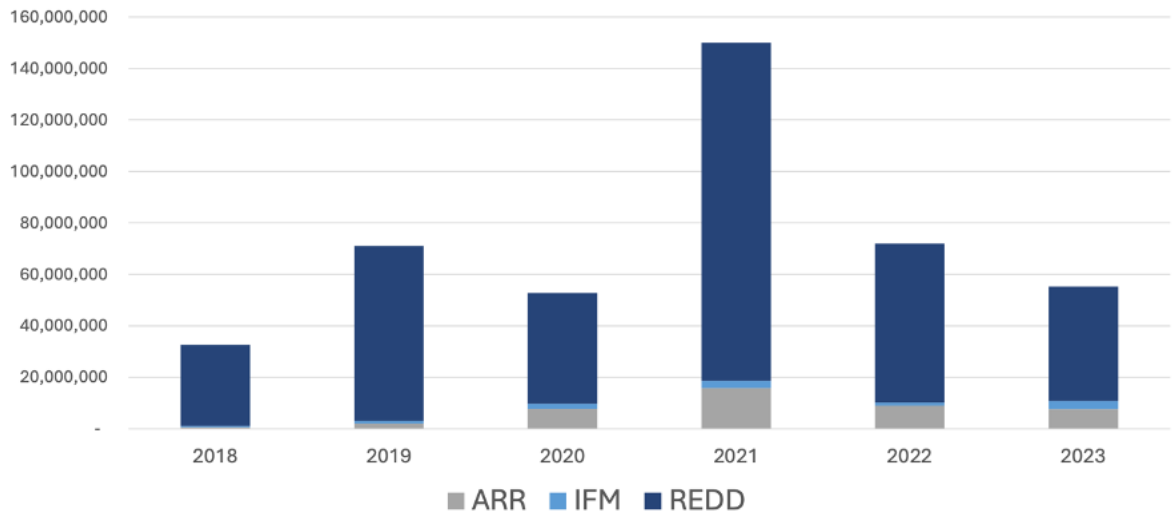

Figure 3. Forest VCC issuance according to different forest measures

Till 2020 global VCC market was dominated by oversupply, but starting 2021 when demand increased several times, the amount of VVC not yet redeemed is diminishing each year.
Strong fundamentals of growing corporate demand, combined with new regulations and standards that will make it harder to generate carbon credits, will flip market conditions from oversupplied to undersupplied in the near term. This would put significant upward pressure on prices, especially for nature-based credits, some of which will be generated in the developed countries (Fig. 4).

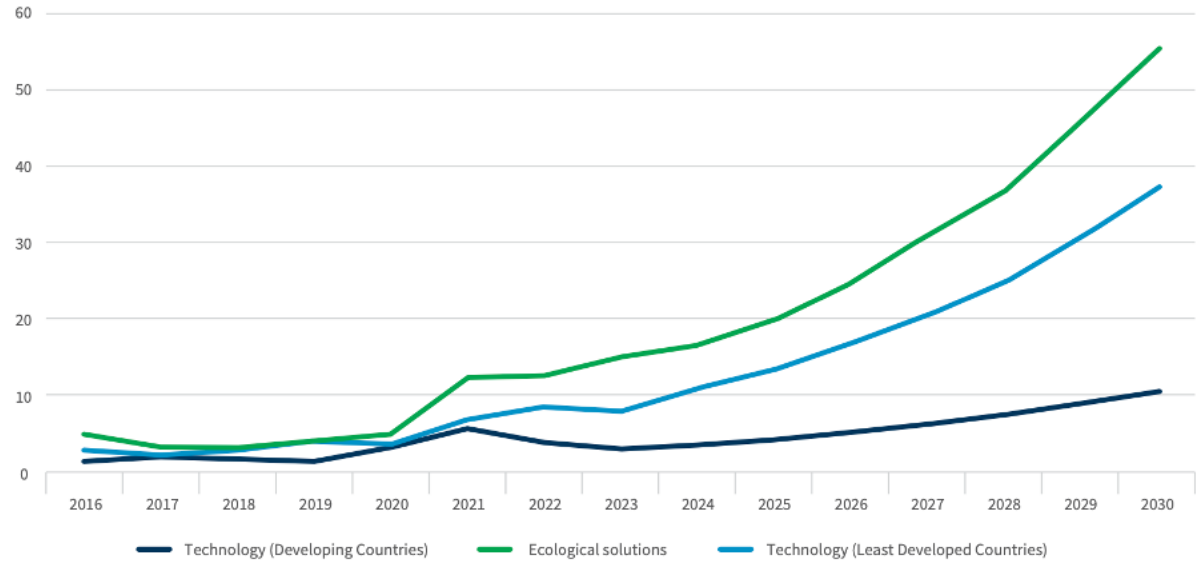

Figure 4. VCC price forecast, tCO_2e (USD)

EU tendencies

EU countries are developing and using a variety of global or local carbon removal methodologies in forestry which leads towards issuing and of voluntary carbon credits, although the number of issued carbon credits issued is rather limited (Table 2).

Table 2. carbon removal methodologies in forestry used by EU countries

Name of the methodology	Completeness	Geographic scope	Standard for validation	Application area
CDM	Applied	Global	Clean Development Mechanism and Verified Carbon Standard (VCS)	Afforestation Includes above and below ground biomass, soil organic carbon
VERRA	Applied	Global	Verified Carbon Standard (VCS)	Afforestation and reforestation
Gold Standard Afforestation / reforestation	Applied	Global	Gold Standard	Afforestation and reforestation, agroforestry
Trees	Applied	Global	TREES	
Spanish carbon footprint registry	Applied	ES	Gold Standard	➢ Afforestation ➢ Reforestation of damaged forests by forest fire
FSC Ecosystem Service procedure	Applied	Italy	FSC – analogues ISO	Ecosystem services Afforestation, reforestation, conservation forestry, sustainable forest management
Label Bas Carbone	Applied	France	*Low carbon label standard*	➢ Aforestation of agricultural and abandoned lands ➢ Reforestation of degraded forests and damaged forests ➢ Conversion into higher quality forests

Hiilinieluntuottajat	Applied	Global/ Finland		Afforestation, sustainable forst management, carbon storage in wood products
Zertiforest	Applied	ES/Finland		Fertilization of forests, increase of rotation, afforestation, thinning, carbon storage in wood products Afforestation of organic soils
Woodland Carbon Code	Applied	UK		Afforestation of mineral soils
LIFE Climate Positive	Pilot	Global		
SNK Cimate Smart management	Pilot	Global	Stichting Nationale Koolstofmarkt (SNK) (Dutch carbon ccredit market)	Resilient forestry CO2 sequestration increase in forests and wood products
LIFE Wood for Future	Pilot	ES		Methodology applied for sustainable forestry
The Forest Solution	Pilot	Sweden	ISO14064:2	Fertilization of forests to increase biomass and carbon storage in boreal forests
SNK Ash forests	Pilot	Netherlands	SNK	Restoration of ash forests
Carbon Capture Company	Under development	Sweden		Carbon storage in boreal forests
Ecosystem Value – Waldwiederaufbau (EVA)	Under development	Germany		Afforestation: ➢ at least three tree species are used ➢ forest species selected according scientific literature
The Global Tree C-sink	Under development	Global	Carbon Standards International (CSI)	Afforestation, involving digital monitoring and verification tools
SILVVACONSULT	Under development	Global	ISO 14064-2:2019	Increase of carbon storage through sustainable management and limited use

Carbon removal certification framework (CRCF)

The EU Commission took initiative to regulate the voluntary carbon market and introduced the Carbon removal certification framework (CRCF), which will include forest measures as part of nature based carbon removal solutions.

There are several ways to remove and store carbon, which will be able to certify under CRCF:

- Nature-based solutions, such as restoring forests, soils, and innovative farming practices.
- Technology, such as bioenergy with carbon capture and storage, or direct air carbon capture and storage.
- Long-lasting products and materials, such as wood-based construction.

To receive certification, the carbon removals will need to be correctly quantified, deliver additional climate benefits, strive to store carbon for a long time, prevent carbon leaks, and contribute to sustainability. CRCF also sets out requirements for third party verification and certification of carbon removals, in order to harmonize the certification process, ensure environmental integrity and build public trust.

The EU certification of carbon removals will be developed in two steps. Firstly, the Commission will set up high-level quality criteria under the proposed Regulation. Secondly, the Commission will approve detailed certification rules for the measurement, monitoring, reporting and verification of carbon removals from both industrial and nature-based activities.

In order to demonstrate that carbon removals comply with the EU quality criteria, operators of carbon removal activities will need to apply to a public or private certification scheme that has been recognised or approved by the Commission. The activities of carbon removal operators will be regularly verified and certified by independent certification bodies that will check compliance with EU rules. This process will result in the issuing of certificates of compliance and in the recording of carbon removal units in public registries managed by certification schemes.

Corporate sustainability reporting directive (CSRD)

Corporate sustainability reporting directive is European Union (EU) legislation, in effect since 5 January 2023, that requires EU businesses—including qualifying EU subsidiaries of non-EU companies—to report on the environmental and social impact of their business activities, and on the business impact of their environmental, social and governance (ESG) efforts and initiatives.

From 2024 to 2028 CSRD reporting will engage more and more companies in the EU and operating in the EU (Fig. 5).

Figure 5. CSRD compliance timeline

Among CSRD reporting items is the carbon footprint of companies and plans for carbon neutrality. According to regulation businesses will be obliged to eliminate their Scope 1 and Scope 2 carbon emissions by changing their business practices, and investing into new technologies. While for Scope 3 (upstream and downstream) emissions they will be able to use carbon credits for offsetting their emissions. It is estimated that offsetting Scope 3 emissions from companies with SBTi (Science based target initiative) commitments and CSRD reporting requirements will boost carbon credit markets substantially (Fig. 6).

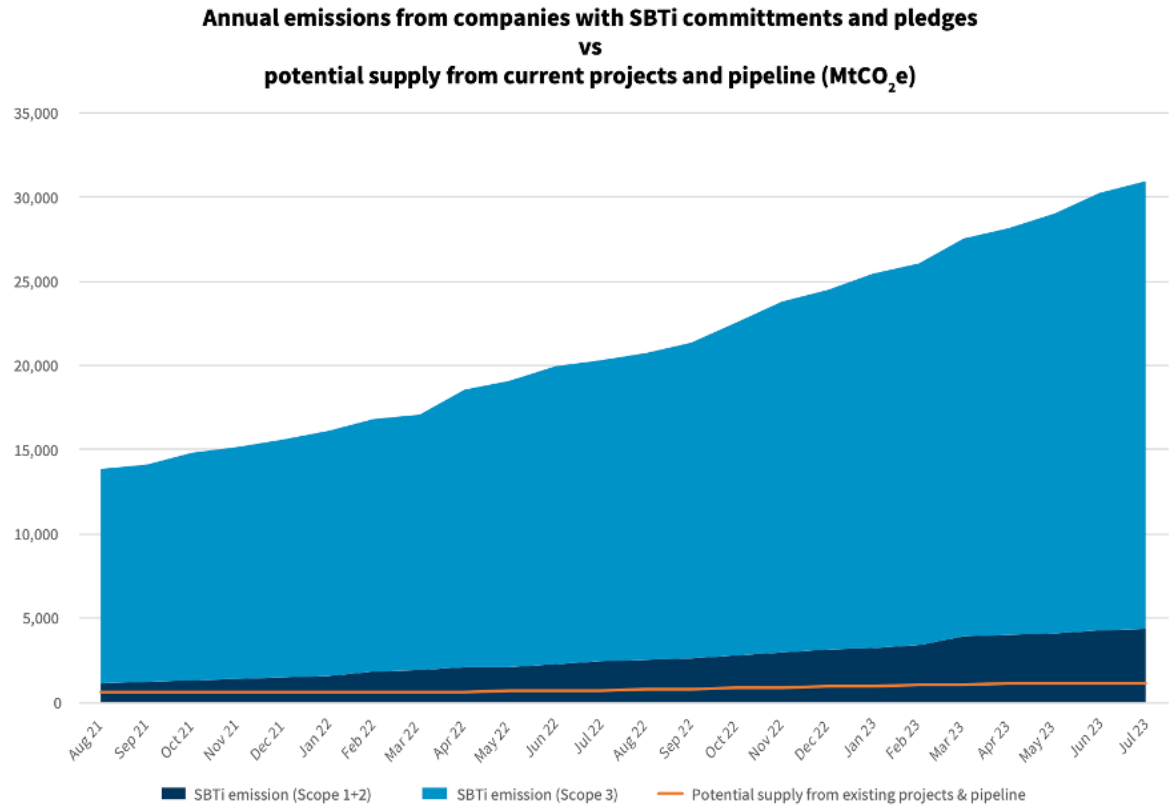

Figure 6. Annual emissions from companies with SBTi commitments and pledges vs potential supply from current projects and pipeline ($MtCO_2e$)

Carbon removal methodologies in afforestation projects

Carbon removal methodologies for ARR projects globally and in the EU are quite similar, because the baseline is quite clear and carbon removal by biomass growth is easy to measure and evident. Similar afforestation methodologies exist in different EU

Based on Verra's Verified carbon standard and carbon removals by afforestation projects includes the following parts:

- Carbon removal by above ground tree biomass (stem, tops and branches) – calculations are based on measurements and nationally accepted estimations – allometric formulas.
- Carbon removals by below ground biomass of trees (stump, coarse roots and fine roots) – calculations are based on coefficients from IPCC guide or scientific literature.
- Carbon removals by leaves – calculations are based on coefficients from IPCC guide or scientific literature.
- Carbon removals by dead wood – calculations are based on coefficients from IPCC guide or scientific literature.
- Carbon removals by Soil organic carbon increase due to land use change – calculations are based on actual soil analysis and models developed or in previous methodologies coefficients from IPCC guide or scientific literature.

As an example, can be Ecobase project (Fig. 7).

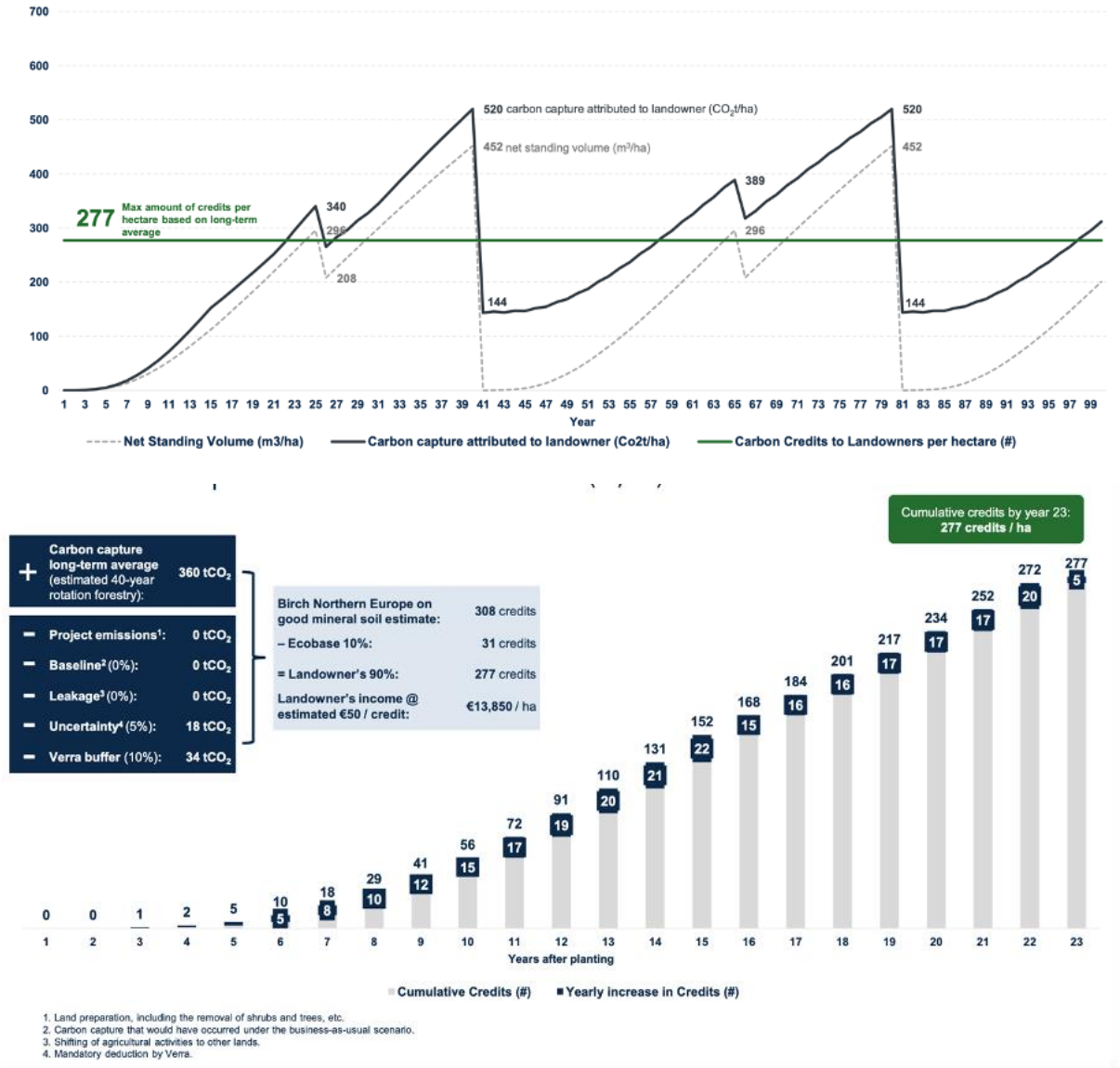

Figure 7. Carbon removals by North European birch (Ecobase project - Latvian case)

Carbon farming in forestry in Lithuania

UNDP JI. The beginning of private forest carbon tool development can be considered UAB "Euromedienos grupė" Joint Undertaking afforestation project, which was approved by national authorities in December 29, 2010 and which targeted to remove 220816 tCO2 during 2010-2031 and to receive corresponding amount of Emission reduction units (ERU) under UNDP JI program. Unfortunately, soon after approval of the project ERU market collapsed, and the project have not requested to issue of ERU.

In Lithuania there has never been any national VCC scheme, therefore forest owners could develop their own projects to register according to global methodologies of VERA and Gold Standard. Because VERRA and Gold Standard project development is costly and can be economically viable only in case of large scale projects, none of such projects was developed in Lithuania.

Currently Lithuanian forest owners have possibilities to join several international projects which have wide coverage over EU markets and are ARR type (afforestation) projects.

Members of LFLOAF, who are involved in afforestation activities, are invited to join **Ecobase** Europe afforestation project to receive voluntary carbon credits, issued based on VERRA's CDM AR- ACM0003

methodology V.2.0. Ecobase Europe afforestation project is under final audit stage and expected to complete registration at VERRA in March, 2024.

Ecobase project offers that landowners can benefit from carbon removal both by establishing traditional forest species as a forest and by planting poplars as agricultural crop.

- Trees are planted on land where the forest before establishment was not growing.
- Carbon credits are eligible for tree rotations not shorter than 20 years.
- At least two rotations have to be grown – meaning that the total land owners commitment to grow trees established on agricultural land should be not shorter than 40 years.
- 10% of generated carbon credits are transferred to intermediary, which develops certified carbon credit project and covers all costs for project development and carbon credit validation – meaning landowner, which establishes poplars, does not need to incur any upfront project development and other carbon issue costs.
- Number of carbon credits and crediting period depend on tree species planted and expected rotations: e.g. birch can receive up to 277 carbon credits (after buffer and intermediaries commissions) over the first 23 years.
- Poplars as agricultural crop over the first 13 years can generate to landowner 210 carbon credits (after buffer and intermediaries commissions) without counting SOC increase.
- The price for carbon removal is assumed at 30 eur/t CO2.

In Lithuania, total 1,389 hectares of the afforestation project area was submitted to Ecobase project for 328,784 credits to be issued from them.

The largest part in that is taken by agricultural crop - poplars. Total 1173 ha of poplar plantations established in Lithuania submitted to Ecobase project are expected to remove 261107 t CO_2 within next 12 years (Fig. 8).

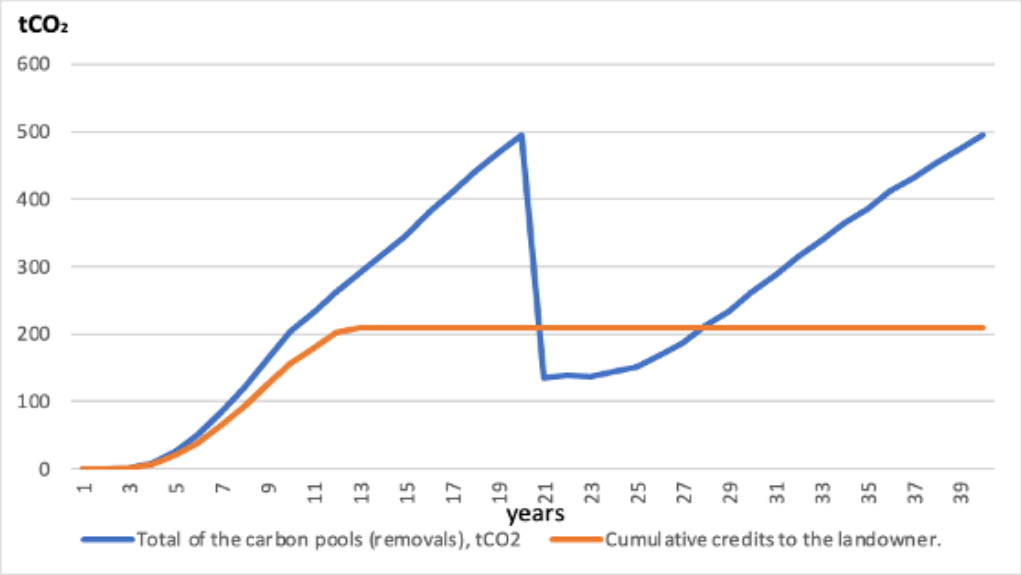

Figure 8. Carbon credit calculations for poplar plantations in Lithuania (tCO_2/ha)

In October 2023 representatives of Ecobase carried out monitoring for verification of Lithuania's 4 year-old poplar plantations. The following results were obtained from monitoring activities:

- 377 ha of 4 year old poplar plantations were monitored and are expected to receive 89 thousand Voluntary carbon credits in the next 12 years.
- 47 sample plots were selected for measuring in 377 ha area, where above ground biomass of 4 year old poplar plantations ranged from 2.8 m^3/ha to 50 m^3/ha, and averaged 21 m^3/ha.

It was estimated that in 4 year since the establishment 377 ha of poplar plantations removed 9420 t of CO_2, and will be eligible for 8478 Voluntary carbon credits after completion of the verification in 2024.

Arbonics. Another company which offers similar to Ecobase project is another Estonian startup – Arbonics, which offers its services with Swedbank loan for afforestation. Members of Arbonics project will receive voluntary carbon credits, issued based on VERRA's CDM AR-VM0047 methodology V.2.0. Arbonics afforestation project.
Currently Ecobase develops improved forest management project for registration at VERRA. Lithuanian forest owners are offered to join Arbonics IFM project as well. The major IFM measures will include conservation forestry by extending rotations, changing of non-native species to native longer rotation species, improving forest stands introducing mixed forest stands instead of monoculture stands, adding a second layer under a single-layer forest etc.

1.4 Carbon Farming R&I activities in EU and progress in Lithuania

Overview of Carbon farming R&I activities

The identification of International projects, initiatives and possible synergies was made in Deliverable 3.1. Mainly, the identification is based on how already achieved results in Lithuania have the potential to be reused in our project. For example, in the BEATLES project, where GFarm for LIFE partners are involved: The synergy of both projects is via sustainable and regenerative agriculture practices (climate-smart farming) and, where BEATLES focuses more on smart agriculture practices with high carbon absorption potential and GFarm for absorption methodology and calculation tools.
FOREST 4.0 (Centre of Excellence to transform the forest environment monitoring), where GFarm for LIFE partners are involved: The results of both projects are closely related. They could complement each other, where Forest 4.0 is more about the research, experiments and technical infrastructure for forest GHG monitoring, and GFarm is more about methodology and calculation tools for GHG assessment.
The Table 3 shows currently ongoing EU projects closely related to common themes, which are aimed at:

- Coordination of and support for current/future carbon farming initiatives.
- Monitoring, reporting and verification (MRV) of soil carbon and GHG balance.
- Other relevant projects.

Table 3. Ongoing EU projects related to common themes

Project name, duration and link	Description
Coordination of and support for current/future carbon farming initiatives:	
ORCaSa  https://irc-orcasa.eu/ Duration: 2022-2025	Organising an international research consortium on soil carbon (incl. non-European partner countries/institutes). The project seeks to address the increasing carbon emissions from human activities, disrupting the balance of organic carbon absorbed and stored in the soil to support plant growth. ORCaSa will expand the scope to include agricultural soil carbon and **soil carbon stored** in **forests, pastures, wetlands**, and urban areas. Coordinated by the French National Research Institute for Agriculture, Food and the Environment (INRAE), the project will be powered by Impact4Soil. This state-of-the-art platform will collect knowledge on **soil carbon** and make it available to the public.
CREDIBLE  https://www.sae-innova.com/credible/ Duration: 2023-2026	Setting up a 'network of networks' for favouring transparency, environmental integrity, and standardisation in soil carbon accounting. The main goal of the CREDIBLE project is to build momentum and trust for implementing carbon farming in the EU. This is achieved by setting up and moderating a network of projects and stakeholders to favour transparency, environmental integrity, and methodology standardisation in soil carbon accounting. Such a network will be responsible for pushing forward multiple discussions (articulated around three main themes: which practises, what standards; how to monitor) and is expected to evolve from a mostly technical/scientific network at the onset of the project into a process catalysing policy-making and business innovation toward its end.
Farms4Climate  https://www.farms4climate.eu/project/ Duration: 2022-2024	Its overall objective is to facilitate the creation and development of community-based organisations that can drive economic growth by flag shipping agroecological carbon farming. This is achieved by developing digital enablers to make carbon farming operational for smallholders and empowering stakeholders through programs designed to inspire systemic change and to promote eco-entrepreneurship and gender-transformative dynamics.
CARBONICA  https://carbonica-hub.eu/i-bec-and-esyd-collaboration/ Duration: 2023 - 2026	Carbon Initiative for Climate-resilient Agriculture. The main objective of this project is to establish CARBONICA Excellence Hub by connecting the innovation ecosystems of Cyprus, Greece and North Macedonia while enhancing their TRL as service providers, based on cutting-edge technologies (Earth Observation – EO; in situ data; digital agriculture etc.) in carbon farming. The main scope is to establish access to excellence to all relevant stakeholders in the QH of the WC, as well as strengthen regional innovation capacity guided by long-term joint R&I strategy in the carbon farming field.
Monitoring, reporting and verification (MRV) of soil carbon and GHG balance:	

MRV4SOC https://mrv4soc.eu/ Duration: 2023-2026	Monitoring, Reporting, and Verification of Soil Organic Carbon and Greenhouse Gas Balance. MRV4SOC is a 3-year funded EU project. It will monitor Carbon farming through its three-pillar Standardization, Reporting, and Verification method. MRV4SOC aims to account for changes in as many Carbon pools as possible, estimate Green House Gases (GHG) and full Carbon budgets, couple Carbon and Nitrogen cycles, quantify Soil Organic Carbon (SOC) accumulation, and assess the results of traditional management practices and Carbon farming. The consortium is investigating methodologies that account for the full GHG and C budget meeting the QU.A.L.ITY criteria (QUantification, Additionality and baselines, Long-term storage, and sustainability). The results of this project will contribute to building a monitoring, reporting, and verification framework for the EU land sector.
MARVIC https://www.project-marvic.eu/ Duration: 2023-2027	Developing and testing a framework for designing harmonized, context-specific Monitoring, Reporting and Verification systems for soil Carbon and greenhouse gas balances by Agricultural activities. MARVIC's mission is to boost faith in European public and private carbon farming (CF) schemes by developing and testing an MRV Framework that will provide any public or private CF scheme developer a standardized approach for designing MRV systems that (i) are in line with the EU carbon removal certification regulation, (ii) have an optimal trade-off between costs and accuracy, (iii) take into account the local context, (iv) reduce administrative burden and (iv) consider risks of non-permanence.
Other relevant projects:	
ClieNFarms https://clienfarms.eu/project/ Duration: 2022-2025	Supporting the transition to climate-neutral / climate-resilient European farming. Innovation Action for climate-neutral and climate-resilient European farms; incl. soil sampling methodology to measure organic carbon. The general goal of ClieNFarms is to co-develop and upscale systemic locally relevant solutions (organisational, financial, technical) to reach climate-neutral and climate-resilient sustainable farms across Europe, interactively integrating and improving existing solutions to achieve economically viable business models in farming systems by involving farmers, extension services, agri-food business, policy-makers, finance and citizens.

ClimateSmartAdvisors https://climatesmartadvisors.eu/ Duration: 2023-2030	This project gathers 1.500 Advisors, 140 Coaches, 27 National Coordinators, and 12 Thematic Leaders in one place, building a community of interested and qualified stakeholders with a common aim to shift the European farming sector to a new level of climate-smarter agricultural practices. ClimateSmartAdvisors is a pan-European multi-actor network covering 27 countries. Its aim is to boost the EU agricultural advisory community, accelerating the adoption of climate-smart (CS) farming practices by the wider farming community within and across EU AKISs. To reach this objective, ClimateSmartAdvisors focuses on the crucial role of advisors in developing and disseminating CS innovations and practices. The project will organize activities focusing on strengthening the advisors' capacity to provide CS advice and boosting their role in the transition towards CS farming through their involvement in innovation projects, CS-AKIS, and EU projects and initiatives.
LIFE C-Farms https://c-farms.eu/ Duration: 2021 - 2023	Supporting the implementation and development, integration of climate and agricultural, environmental and energy policy and legislation. To accomplish its objectives, C-FARMs will involve public Institutions, University/research centres, private companies and farmer/woodworking industry associations working specifically on themes related to the LULUCF sector.
BIOCOMP https://cordis.europa.eu/project/id/101075426 Duration: 2023-2028	Consequences of global biodiversity loss and climate change for decomposer communities and implications for forest carbon fluxes. The BIOCOMP project will bring about a new level of understanding of how biodiversity and carbon cycling in forest ecosystems worldwide will change as a result of climate change and land use, and it will provide the data and strategies to tackle one of the most pressing challenges of current climate and forest policy.
SEQANA https://www.seqana.com/ Duration: 2022 - 2025	**Tailor-made software solution to improve nature-based solutions that fight climate change.** Soil organic carbon (SOC) content is a convenient proxy for soil health, productivity, and resilience. Sequestering carbon in soils can be an important step in mitigating climate change by reducing atmospheric CO2 and building healthier ecosystems. Carbon certificates (insets and offsets) can effectively finance Nature-based climate solutions like soil regeneration. For dependable certification, developers of SOC projects need reliable and affordable measurements. Current compulsory monitoring, reporting, and verification methods are restrictively costly and time-consuming. The EU-funded Seqana aims to unlock the potential and maximise the impact of SOC by delivering a low-cost, highly accurate, and farmer-friendly satellite-assisted Software-as-a-service solution.

C-Sink https://c-sinkproject.eu/ Duration: 2023 - 2027	Actions required to secure the large-scale deployment of the leading CDR approaches to meet EU climate targets. The C-SINK project aims to deliver to the EC a complete package of worked-up proposals to support a new or amended European legal/regulatory framework to bring high-quality CDRs into the market. That package will contain pre-standards (in CEN format) covering requirements and methodologies for sampling, testing and QMS (ISO9000) upon which to build monitoring, reporting and verification systems. It will also include proposals to cover (a) environmental, social-impact and governance issues and (b) the means of building trust in the market. This will encourage entrepreneurs to demonstrate effective and safe CDR projects and to make large investments, thus allowing the market to evolve to tackle the climate crisis. The C-SINK consortium includes organizations from 11 countries with complementary skills and expertise in the different CDR technologies, the writing of CEN and ISO standards, climate law, carbon trading, and all of the relevant environmental and social issues.

Carbon credit activities in Lithuania

DOJUS agro has been officially collaborating with Estonian company eAgronom since 2022, which started its activities in 2016. Even before 2022, DOJUS agro actively sought ways to help farmers change their farming practices and invest in regenerative farming solutions. While communicating with farmers, DOJUS precision AG team realized that many farms are undergoing a certain transformation and are changing their farming practices. This is also confirmed by the soil sampling service expansion done by DOJUS agro since 2019. The changes in the soil observed during a series of soil tests and results supported farmers' decisions to change farming practices. This led to the official collaboration between the two companies. The companies collaborate with a common goal - to help farmers choose good agricultural practices solutions with knowledge, digitization, and additional incentives from the voluntary carbon credit market.

eAgronom

Methodology. DOJUS agro, in collaboration with eAgronom, provides crop farms with the opportunity to receive compensation for generating high-value voluntary carbon credits. Due to very high methodological standards and measurable contributions to carbon sequestration, this project is trustworthy among other initiatives to offset GHG emissions. The methodology is based strictly on measurable additionality, empowering positive natural processes. Applied additional farming practices are verified by satellite data and actual carbon level testing in the soil. To meet the highest standards, the entire process is aligned to fit "Verra" standards, that verifies all project data submitted and issues certificates for calculated carbon credits. This project is only working with crop farms and is separated from dairy farms, forestry or other processing and production processes.

Program certification. "Verra" (verra.org) is a non-profit organization founded in 2007, whose goal is to create and approve high-quality standards and methodologies for generating carbon credits. Its main activity result is the Verified Carbon Standard (VCS). The Verified Carbon Standard (VCS) program is the most widely used greenhouse gas (GHG) crediting program in the world. During certification, the "Verra" organization ensures that all processes are implemented without fraud or carbon leakage and that real change is truly done. It also promotes financing for activities that reduce and eliminate emissions, improve livelihoods, and protect nature. More than a billion tons of carbon and other GHG emissions have been removed or reduced from the atmosphere through VCS projects. The VCS program is a very important and constantly improving part of environmental protection.

Carbon sequestration market in Lithuania. The "eAgronom" agronomist team carefully analyzes the individual farm practices and its ability to meet carbon sequestration "additionality" criteria. It considers

not only the farm's technical capabilities but also openness and readiness for change. "eAgronom" has various tools (such as farm management platforms) for entering data required to obtain carbon credits. The company's tools are also constantly being improved and adapted to the requirements of certification bodies and farmers' needs. The company invests heavily in ensuring that the farmer receives reliable and accurate calculations of their accumulated carbon credits. Trials are also conducted to apply the latest information on the possibility of accumulating additional carbon credits.

Experience over 2 years in the market. Over 2 years, we have enrolled 28 farms in the program, whose sizes and regions are very diverse. These farms estimate generating over 15,000 certified carbon credits (CRUs). At the same time, 15'000 tons of CO_2 are removed from the atmosphere each year. Farmers' experience in this program is positive, and most of them understand the benefits of changes for soil quality and the environment.

Process over the years. Farmers who register for the program must submit data for the current year and the previous three seasons to set a baseline. Soil tests are performed in the fall, and the results are obtained from the laboratory by December. By January 1st, farm data will be collected. Then, data verification is carried out using satellite data. In March, all data should be checked, and the entire program should be submitted to the "Verra" organization for certification. Certified carbon credits are issued for sale during the summer.

Value, quality, and price of credits. In the long-term trend of the carbon credit market, a price increase is expected. The number of companies that are looking to offset their GHG emissions is increasing. Companies want to invest only in trustful projects implemented on the farms, so usually only certified carbon credits are purchased. Industrial companies buy certified carbon credits on the market for ~35 EUR/CRU. However, this price may vary depending on the project itself.

Other carbon Farming and Credits initiatives in Lithuania

Another significant effort is Lithuania's adoption of the MoorFutures Carbon Standard, initially developed in Germany in 2010. This standard focuses on re-wetting drained peatlands to mitigate carbon dioxide emissions. It operates on the voluntary carbon market, allowing individuals and entities to offset their carbon footprint by funding peatland rewetting programs. Wetlands International Europe and the Michael Succow Foundation have supported the adaptation of this certificate for use in Lithuania. This involves translating the MoorFutures standard and methodology into Lithuanian, legal analysis to ensure project feasibility, selecting pilot sites for carbon projects, and setting up monitoring schemes for greenhouse gas emissions and biodiversity, among other initiatives. The project aligns with the European Commission's Carbon Farming initiative, highlighting peatlands as a key mechanism for carbon farming.

HeavyFinance, a European climate tech investment marketplace, has combined its innovative financing models, including Green Loans, with Agricarbon's automated soil carbon measurement technology. This union aims to promote the transition to regenerative farming practices, offering greater returns on investment for investors and making sustainable practices more accessible to farmers. The collaboration seeks to test new stratification methodologies and address previous challenges in direct measurement across extensive agricultural lands, all under an established international protocol for offsets.

HeavyFinance is deeply involved in soil sampling as part of its carbon farming initiatives, working closely with **Agricarbon**, a soil organic carbon measurement specialist. This collaboration aims to accurately assess changes in soil carbon stock, leveraging advanced technologies for precise measurements. Their joint efforts support HeavyFinance's broader goal of promoting sustainable agricultural practices and contributing significantly to carbon sequestration efforts

Agreena is making significant strides in carbon farming in Lithuania and across Europe. The company has developed a pioneering soil carbon platform that now encompasses two million hectares of farmland across 17 European countries, including Lithuania. This platform, AgreenaCarbon, supports farmers in their transition to regenerative agriculture, enabling them to contribute actively to climate

crisis mitigation by removing carbon from the atmosphere and storing it in their soils. Agreena leverages advanced science and technology to transform climate-friendly farming efforts into high-quality carbon removal credits, providing an essential revenue stream for farmers. This initiative is backed by cutting-edge measurement, reporting, and verification (MRV) technology, incorporating remote sensing and AI to enhance its capabilities.

Agreena and Baltic Agro have initiated a strategic partnership in Lithuania, marking a significant step towards sustainable agriculture in the region. This collaboration focuses on financially rewarding Lithuanian farmers for their carbon sequestration efforts through Agreena's carbon farming platform. The partnership aims to encourage adopting climate-friendly farming practices by issuing carbon certificates, which can be a new source of income for farmers engaging in regenerative agriculture.

Climate Farm Demo

The Lithuanian Agricultural Advisory Service (LACS) is involved in the international project "Climate Farm Demo", which involves 25 Lithuanian crop and livestock farms. This project creates a network of 1 500 pilot farms in Europe for advanced farming that contributes to climate change mitigation. Advisors use digital tools including the Cool Farm Tool and Cap'2er to assess and reduce greenhouse gas emissions.

During the project, LFCC advisors will provide free advice on 25 farms and analyse the digital tools to develop individual emission reduction plans. On-farm field days will allow them to share their results with farmers.

As part of the project, selected Greenhouse Gas (GHG) calculators, Cool Farm Tool and Cap'2er, will be used to assess farm emissions. This is an important step given that the National Climate Change Management Agenda foresees the establishment of a GHG accounting system in Lithuania by 2025.

The event highlighted the global relevance of climate change and the initiatives taken by European countries in this area. Lithuania's agriculture and forestry, although sources of greenhouse gases, can also contribute to their neutralisation. Adaptation to climate change is important and can be achieved through a variety of measures, thereby increasing economic benefits and reducing climate impacts.

KURKLT.LT

The initiative of this project aims to harness the potential of the land use, land-use change, and forestry (LULUCF) sector in reducing significant CO_2 emissions from the atmosphere. As a European Union member state, Lithuania has committed to reducing greenhouse gas (GHG) emissions, particularly in the LULUCF sector, by 2030. To achieve these goals, it is crucial to implement sustainable land management practices that not only reduce emissions but also compensate for them.

The main problem addressed by this project is how to incentivize the LULUCF sector to adopt sustainable land management practices and increase the sequestration of CO_2 in living biomass, dead organic matter, and soil. The European Commission's "Sustainable Carbon Cycles" communication highlights the carbon farming initiative as a way to reward land managers for implementing these sustainable land management practices.

1.5 Climate Change Management Policy: Objectives and Challenges

The "Climate Change Management Policy: Objectives and Challenges" is a comprehensive approach undertaken by the Ministry of Environment of the Republic of Lithuania. This policy is meticulously crafted to align with the European Union's ambitious "Fit for 55" package and Lithuania's national objectives. It aims to significantly reduce greenhouse gas (GHG) emissions, targeting a 30% reduction by 2030 compared to the levels in 2005, with the ultimate goal of achieving climate neutrality by 2050.
Objectives:
Reduction in Transportation Emissions: Transportation, being the largest contributor to GHG emissions in Lithuania, is at the forefront of the policy's objectives. The plan involves substantial investments in renewable energy sources and advanced technologies to meet the 2030 emissions reduction target.
Compliance with ETS and Non-ETS Sectors: The policy delineates strategies for sectors within the EU Emissions Trading System (ETS) — notably chemicals, oil refining, and energy production — which together account for 50% of Lithuania's GHG emissions. It also addresses non-ETS sectors like transport, agriculture, and industry, outlining specific reduction goals for each.
LULUCF Sector Targets: The policy commits to achieving a -0.661 million tons CO_2 eq. annual absorption by 2030 under the Land Use, Land-Use Change, and Forestry (LULUCF) regulation, contributing to the EU's wider absorption goal. It highlights the necessity of existing and additional policy measures to overcome the challenges in this sector.
EU CO_2 Absorption Certification: A key objective is to encourage high-quality CO_2 absorption through a certification system based on sustainability and long-term storage criteria. This system aims to support the transition to a new EU LULUCF goal between 2026 and 2030.
Economic and Investment Strategies: Addressing the economic aspects, Lithuania plans to divert from its significant annual expenditure on fossil fuels towards investing in renewable energy and technology. This strategic shift not only aims at emission reduction but also seeks to stimulate economic growth through sustainable investments, promoting energy independence and technological efficiency.
Sector-Specific Emission Reductions: The ambitious targets set for both ETS and non-ETS sectors pose a significant challenge, requiring a balanced approach to technological advancement and sector-wide cooperation.
LULUCF Sector Compliance: Achieving the stipulated LULUCF absorption goals demands overcoming substantial hurdles, given the current projections and the need for intensified policy measures.
Investment and Economic Reorientation: Mobilizing the necessary financial resources for renewable energy and new technologies presents a considerable challenge, compounded by the need to ensure public engagement and cross-sector integration.
Sustainability and Long-Term Goals: The policy's success hinges on its ability to not only achieve short-term objectives but also to set a sustainable path toward 2050 climate neutrality, necessitating ongoing adjustments and societal support.
The "Climate Change Management Policy" of Lithuania presents a forward-looking framework aimed at addressing the pressing issue of climate change. While its objectives are clear and aligned with broader EU goals, the challenges it faces underscore the complexity of transitioning to a sustainable, low-carbon economy. Success will require unwavering commitment, innovative solutions, and collaborative effort at both national and international levels.

1.6 Policy Relevance of Carbon Farming in Lithuania

In Lithuania, the advancement of carbon farming practices is being pursued with vigor as a strategic measure to counteract climate change and promote sustainability within the agricultural sector. This initiative, strongly supported by the Ministry of Agriculture of the Republic of Lithuania, aims to integrate ecological systems and innovative agricultural practices to reduce carbon footprints and enhance the sector's sustainability.

Strategic Planning and Ecological Practices:

- The strategic plan for 2023-2027 places a strong emphasis on the implementation of ecological systems, such as crop rotation and the reclamation of unused agricultural land into meadows, which are essential for the adoption of carbon farming practices.
- These methods are not just pivotal for transitioning towards sustainable farming but also act as effective mechanisms for carbon dioxide sequestration, showcasing the potential of meadow maintenance and wetland management schemes in providing biodiversity benefits and facilitating carbon capture.

Innovative Projects and Policy Directions:

- The "Build for Lithuania" project is a cornerstone effort in evaluating the carbon storage capabilities of Lithuania, aiming to enhance understanding at both the EU and national levels and to scrutinize existing carbon farming schemes.
- Alongside, the MTTV project conducted by the VDU Agriculture Academy focuses on modeling to develop a comprehensive national accounting and green certificate system. This initiative is designed to accurately measure and manage greenhouse gas emissions and their absorption, marking a significant step towards environmental accountability and sustainability.
- Policy directions are aligned with promoting sustainable land use, advocating for soil management practices pertinent to carbon farming, and facilitating the implementation of electronic administration systems. The certification of CO2 absorbents is encouraged to ensure the generation of high-quality carbon sinks, thereby supporting transparency and sustainability in agricultural practices.

Objectives, Threats, and Challenges:

- **Economic Viability and Coherent Policies:**
  - Economic viability stands as a primary objective, emphasizing the need for the benefits of carbon farming to be clearly visible and tangible within the agricultural sector. The approach to carbon farming is framed as an opportunity that comes with its own set of risks, notably the small and volatile market for carbon credits in Lithuania, which could lead to market instability.
  - Efforts are directed towards creating a coherent and balanced policy framework that not only incorporates sustainable farming practices but also makes use of final certificates to ensure a stable and supportive environment for carbon farming.
- **Navigating Uncertainties:**
  - The journey towards fully integrated carbon farming practices is fraught with uncertainties, mainly due to the unpredictable nature of climate change and the fluidity of policy landscapes. These uncertainties, coupled with market instability and the absence of international standards, pose significant risks to farmers and can impede progress in the field.

The policy relevance of carbon farming in Lithuania is underscored by a comprehensive strategic approach that combines ecological practices, innovative projects, and forward-thinking policy directions. Despite facing challenges and uncertainties, the push for carbon farming reflects Lithuania's commitment to sustainability and the proactive steps being taken to mitigate climate change impacts within the agricultural sector.

1.7 Overview of Successful Projects and Examples from Other Countries

The most important EU projects are presented in Table 4.

Table 4. Successful EU projects and examples

Project Name	Description	Link
Land Use and Management for Sustainable Governance Under Climate Change (LAMASUS)	Improving land use and management for sustainable governance under climate change.	https://www.lamasus.eu/
Land-based Mitigation for Resilient Climate Action (LANDMARC)	Evaluating the climate impact potential of land-based negative emission solutions.	https://www.landmarc2020.eu/
National Determined Contributions: Analysis for Systemic Transformations (NDC ASPECTS)	Assessing sectoral perspectives on climate transitions for NDCs.	https://www.ndc-aspects.eu/
Comprehensive CO2 Observation Network (CoCO2)	Monitoring and verifying anthropogenic CO2 emissions with a prototype system.	https://coco2-project.eu/
Earth System Modelling for 2025 (ESM2025)	Advancing Earth system numerical modeling for climate process representation.	https://www.esm2025.eu/
Climate Neutral Farms (ClieNFarms)	Developing climate-neutral and resilient sustainable farms.	https://clienfarms.eu/

2. Best research practices assessment for GHG emission estimation and monitoring in agriculture

2.1 GHG emissions from transport in agriculture

Non-Road Mobile Machinery (NRMM) are used in many sectors for various off-road activities. NRMM includes many types of machines (Harvesters, Tractors, Loaders, Excavators, Bulldozers, Cultivators, Lawnmowers, etc.) with or without body and wheels, with a combustion engine, and are not intended to carry passengers or goods on the road (Hagan et al., 2023). Tractors are the most studied machines of the agricultural NRMM, because they are the most polluting agricultural machinery (EPA Research Report, 2022; Janulevičius et al., 2013). Hou et al. (2019) analyzed the emission characteristics of 22 different types of agricultural NRMMs, including combines, tractors, and micro-cultivators. They found that in Beijing in 2016 tractors accounted for more than 80% of agricultural NRMM emissions. Another very important topic is how to improve methods for agricultural NRMM emission studies to reflect real pollution conditions. Several studies have evaluated differences in NRMM emissions between real field and laboratory conditions. Pirjola et al. (2017) determined the exhaust emissions of a tractor under real field conditions and compared it with the exhaust of a similar engine in the laboratory. They found that NOx emission factors under real conditions were approximately 50% higher than under laboratory conditions. Because of the serious consequences of emissions from NRMM in agriculture, much previous research has focused on mitigation and emission reduction. Lovarelli and Bacenetti (2019) described several technological solutions suitable for agricultural tractors and self-propelled machines. The output of these solutions may include examples of devices such as diesel particulate filters, exhaust gas recirculation and selective catalytic reduction devices.

The process of collecting data and information on agricultural NRMM can be done using two main methodologies. The main method is direct contact with potential data holders and data sources. The data required for the evaluation may include the following specific data about the NRMM: manufacturer, type of NRMM, age of the NRMM, number of machines of this type, EU approval number, engine size, power (kW), fuel used and where it is purchased, annual fuel consumption and annual operating hours hours. A secondary method may be to search the internet for available databases and datasets, such as statistical offices, etc. The initial analysis includes the calculation of CO2 emissions according to the Tier 1 calculation method with the values shown in Table 5 (EPA Research Report, 2022).

Table 5. Values used for Tier 1 CO_2 calculations (EPA Research Report, 2022)

Fuel	kg CO_2 litre^{-1}	kg CO_2 kg^{-1}	g CO_2 MJ^{-1}	g CO_2 kWh^{-1}	MJ tonne^{-1}	litres tonn $^{-1}$ e
Petrol	2.36	3.121	70.00	251.9	44,589	1325
Diesel	2.68	3.174	73.30	263.9	43,308	1183
Kerosene	2.52	3.156	71.40	257.0	44,196	1250

Tier 2 requires fuel type and emission factors based on a more detailed classification to estimate emissions. Tier 3 requires a much larger amount of information, but this tier allows for much more accurate emission estimates (EPA Research Report, 2022)

There are practically no environmental impact studies of tractors and other off-road machines that directly determine greenhouse gas emissions in Lithuania. Some researchers have studied the changes in fuel consumption of tractors in various transportation jobs. And this is also very important, because fuel consumption can be directly linked to GHG emissions. Fuel consumption, and thus the

environmental impact, is highly dependent on various parameters, e.g. tractor driving speed, engine speed, wheel slip, road or field surface, etc. (Juostas et al., 2008) conducted research and found that at lower tractor driving speed the driving wheel slippage would be bigger. During tractor transport works under different road and field conditions, economic engine working conditions or nominal power could be fully used by choosing suitable unit proportion and driving speed. Working at reduced engine speed can cut fuel consumption by 5%.

Fuel consumption varies considerably depending on engine speed. Many tractors can reach optimal fuel consumption at reduced engine speed. To determine how much fuel could be saved when tractor works at engine speed of 2 300 rpm and after when engine is working at 1800 rpm, test measurements on stubble (driving speed – 8 km/h) and graveled road (driving speed – 18 km/h) were taken (Janulevičius et al., 2019). At different engine speed the same driving speed was reached and 4.5–5.0 % of fuel saving was determined (Fig. 9).

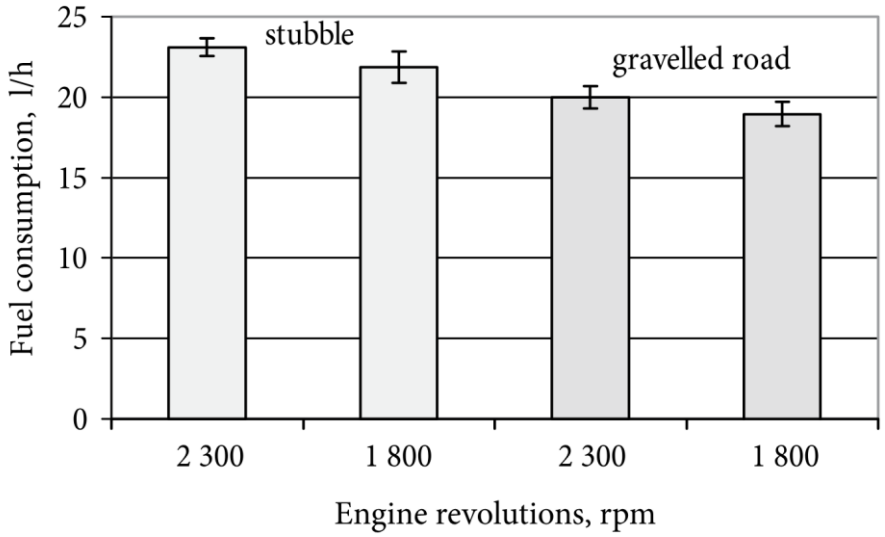

Figure 9. Fuel consumption at different engine speed, when driving speed on stubble – 8 km/h, on gravelled road – 18 km/h (Janulevičius et al., 2019)

Hourly fuel consumption of transport unit is recalculated to fuel consumption in l/100 km. From diagram (Fig. 10) of engine load and fuel consumption at transport work it can be seen, that fuel consumption of 330 l/100 km at driving speed of 2 km/h was determined. Then engine has worked at very low torque. At chosen steady engine speed (1800 rpm) most economical working condition was reached. At driving speed of 34–37 km/h, fuel consumption was 70 l/100 km, and engine load has reached its maximum value – 100 % of engine load (Janulevičius et al., 2013).

Knowing the tractor fuel consumption, as one of the most important parameters in agricultural transport work, it is possible to calculate the environmental impact in terms of CO_2eq. Many Lithuanian scientists use the equivalent of 2.76 kg of CO_2 for one liter of diesel fuel when assessing the impact on the environment (Saldukaitė et al., 2022).

In the course of the project - Evaluation of energy consumption and GHG emissions using conventional and robotic ecological technologies for sugar beet crop care - performed conventional and robotic ecological analysis of research papers on sugar beet crop care technologies evaluated by robotic technologies impact on energy indicators and GHG emissions, performed by different comparative assessment of technologies (Lithuanian Science…, 2021).

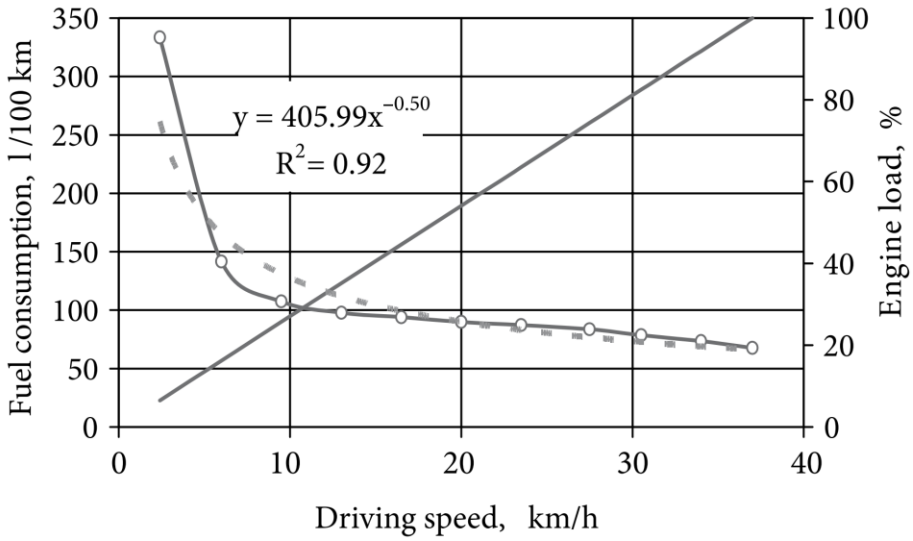

Figure 10. Dependence of engine load and fuel consumption on driving speed at transport work

2.2 Soil tillage impact on GHG emissions

Tillage, all technological operations that mechanically disturbance the soil to prepare seedbeds, has a direct and indirect impact on emissions. Direct emissions are due to the fuel used for tillage, which depends on a number of factors, including soil properties, tractor size, implement used and depth of tillage. Fuel demand increases with ploughing depth and tractor speed. Direct fuel consumption is also higher on heavy than on light textured soils and increases with increasing soil cone index (Lal, 2004).

The impact of no-tillage on GHG is a controversial issue, as the results of several studies are contradictory and vary according to location, climate, soil type and other factors, and further research is needed to ensure success (Chataut et al., 2023). Shakoor et al. (2021) conducted a global meta-analysis of 50 peer-reviewed publications and found that in different climate zones, no-till management practices significantly increased CO_2, N_2O and CH_4 emissions by 7.1%, 11.9% and 20.8%, respectively, compared to conventional tillage (CT). However, this increase in greenhouse gas emissions can be reduced by long-term no-till practices. On the other hand, no-till reduced the overall GWP of GHG emissions by 7.5% compared to CT (Shakoor et al. 2021). The results of Yue et al. (2023) showed that reduced tillage increases GHG emissions and reduces yields, while no-till reduces GHG emissions but does not reduce yields. These results suggest that no-tillage is an effective sustainable crop management practice for mitigating climate warming and ensuring food security. A reduced tillage system, such as disc cultivation, can significantly reduce GHG emissions from diesel consumption without affecting wheat yields. A study by Stošic et al. (2021) shows that disc harrowing, in particular, and no-till can be recommended as a convenient agricultural practice that helps to restore an optimal balance between GHG emissions, yield and excess nitrogen.

A number of Lithuanian scientists have studied the influence of tillage on GHG emissions. Several dissertations in the field of Environmental Engineering have been prepared and articles have been published in high-level journals referenced in the Clarivate Analytics Web of Science (CA WOS) database. The effects of tractor work processes on the environment were mainly studied by Prof. of the Faculty of Engineering of VMU Algirdas Janulevičius team. The impact of tillage and sowing technological operations on emissions from soils and from agricultural machinery was studied by dr. Sidona Buragienė, dr. Vilma Naujokiene, dr. Lina Saldukaitė-Sribikė and other scientists.

In order to improve tillage efficiency and reduce the impact of the tractor on the environment, it is important to scientifically understand the relationship between the dimensions of the cultivated field and the operational indicators of the tractor between the tillage performance indicators of the tractor

(tractor working time efficiency, work efficiency, fuel consumption, engine power utilization), engine control unit data and field dimensions (Janulevičius et al., 2023).

Contributing test results showed that in the ploughing process, the main amount of fuel was consumed, and CO_2 emitted during technological process of ploughing, and CO – during the work at headlands. Large quantities of NO_x are formed during the technological process of ploughing, and significant quantities – when working at headlands (Fig. 11). Technological process of ploughing amounted to 74.8%, and work at headlands amounted to 25.2% of total duration of the test. In the process of ploughing hourly fuel consumption was 24.03 kg/h. Of these, 92.09% of fuel was consumed for the technological work, and 7.91% – for the work at headlands. Exhaust emission components in the technological process of ploughing and in the work at headlands distributed as follows: NO_x – 69.4% and 30.6%; CO – 16.5% and 83.5%; CO_2 – 84.6% and 15.4% (Janulevičius et al., 2013).

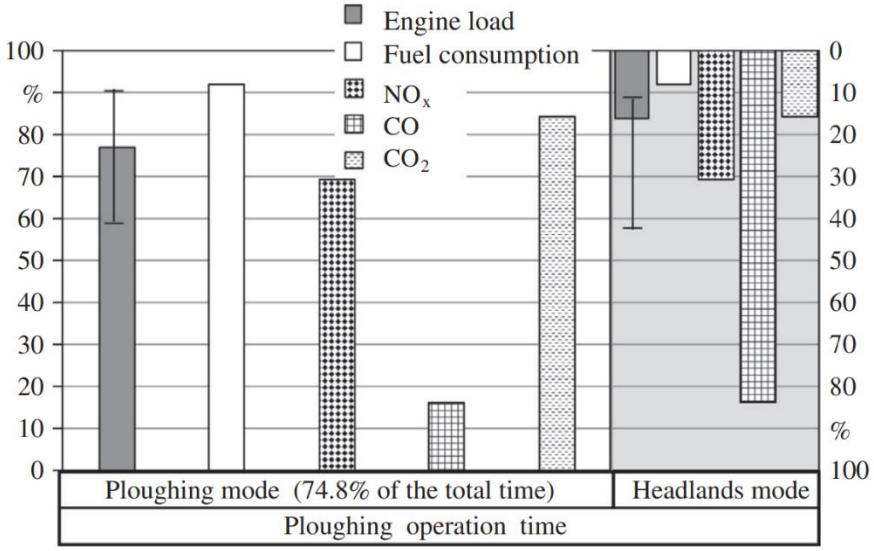

Figure 11. Percentages of tractor performance indicators by the modes of ploughing process (Janulevičius et al., 2013)

In the process of ploughing, when tractor engine speed was reduced and the transmission ratio was selected accordingly to get the set working speed, fuel consumption decreased, CO and CO_2 emissions varied slightly, but NO_x emissions increased significantly. When tractor engine speed was reduced from 2200 rpm to 1600 rpm, hourly fuel consumption in the process of ploughing decreased from 26.59 kg/h to 21.03 kg/h, while NOx emission increased from 532 g/h to 728 g/h. In the process of ploughing the significant part of exhaust oxides was emitted while working at headlands. During the headlands' operating mode, hourly NO_x emission was approximately 770 g/h, CO_2 – 74.6 kg/h and CO – 1765 g/h (Janulevičius et al., 2013).

Ploughing of fields with lengths of 200, 300, 500, 750, and 1000 m resulted in time efficiency values of 0.56, 0.67, 0.78, 0.84, and 0.88, respectively. Regression analyses confirmed that the tractor productivity, engine power utilisation coefficient, hourly fuel consumption, and CO_2 and CO emissions during the whole ploughing process perfectly correlate with the time efficiency factor according to a linear equation model; the fuel consumption and CO2 and CO emissions per hectare correlate with the time efficiency factor according to an exponential equation model (Janulevičius et al., 2019).

Land cultivation work is difficult and at the same time very energy-intensive, requiring a high-powered tractor. Fuel consumption, and at the same time the emission of greenhouse gases into the environment, depends on the technological parameters of tillage: tillage depth, working width, speed, soil properties. Buragienė, et al. (2013) claims that sustainable tillage technologies (shallow ploughing, deep cultivation, shallow cultivation, and direct sowing) reduce CO_2 gas emissions from the soil compared to conventional deep tillage technology. In sustainable tillage technologies, CO_2 emissions

from the soil after autumn tillage ranged from 9.1 (shallow plowing) to 23.4% (direct seeding), after spring tillage from 3.5 (shallow tillage) to 11.5% (direct sowing) and during the vegetation period from 6.1 (shallow plowing and deep cultivation) to 16.1% (direct sowing) lower compared to conventional deep plowing tillage technology.

V. Naujokienė (2018) states in her PhD thesis in Environmental Engineering that more than 40% of the energy consumption in growing agricultural crops is related to the tillage system, where the most energy-intensive and environmentally polluting technological operation is traditional deep tillage (plowing with a plough). She found that when the soil is exposed to biopreparations, the physical properties of the soil (hardness, density, and general porosity) change, which leads to a reduction in tractor fuel consumption for shallow and deep tillage. Naujokienė's research (2018) showed that the highest efficiency of biopreparations in reducing fuel consumption and CO_2 gas emissions was found in shallow tillage - 22.99%, in deep tillage - 23.5%. The most effective biopreparations consisted of phosphorus, potassium, two types of microorganisms and algae extract (Fig. 12).

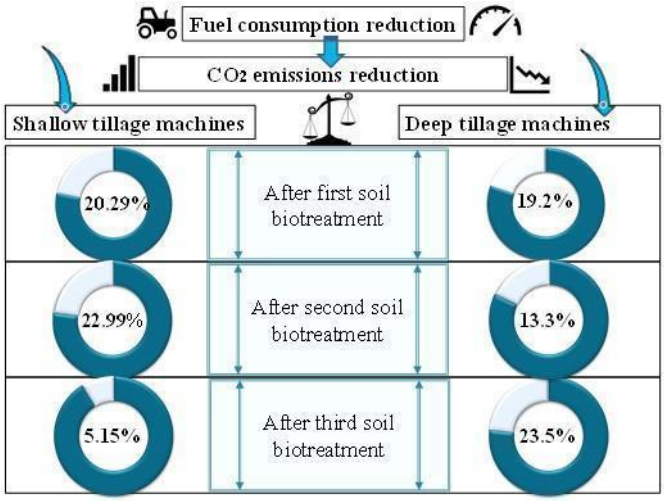

Figure 12. Biopreparation effectiveness for reducing fuel consumption and CO_2 (Naujokienė, 2018)

Saldukaitė-Sribikė (2023) conducted research to determine the influence of different tillage and sowing technologies on fuel consumption and CO_2 emissions from tractors and from the soil: deep tillage, strip tillage and sowing, direct sowing. First, the concentration of CO_2 in the soil was determined, and CO_2 emissions to the environment after sowing and during the vegetation of winter wheat and winter rape. Studies have shown that the concentration of CO_2 in the soil was the highest in the direct seeding technology because the soil is not moved in direct application. However, when analyzing emissions from soil, the results were opposite. When applying strip tillage and seeding technology, CO_2 emissions to the environment from the soil were on average 10 to 16% higher than when applying direct seeding. Compared to traditional tillage, soil CO_2 emissions were up to 16% lower with direct seeding technology (Saldukaitė-Sribikė, 2023). After carrying out the assessment of the life cycle analysis of winter plants, it was found that CO_2 emissions to the environment, when applying strip tillage technology in shaved soil and completely uncultivated cultivated soil, were up to 23.4% lower compared to close soil. Strip tillage reduces CO_2 emissions from the soil compared to full tillage with traditional tillage.

2.3 Other technological operations (fertilizer, spraying) impact on GHG emissions

The impact of other agricultural technological operations on the environment is usually calculated by assessing how much machine energy, fuel, fertilizers, pesticides, or other materials are used to perform those technological operations. Worldwide and in Lithuania, calculations were made using the following carbon dioxide equivalents (CO_2eq) (Table 6).

Table 6. Carbon dioxide equivalent values of agricultural inputs

Agricultural inputs	CO_2 equivalent	Unit	References
Agricultural machinery	0.071	kg CO_{2eq} MJ^{-1}	Pishgar-Komleh et al., 2012; Saldukaite et al., 2022; Šarauskis et al., 2019; Juknevičius et al., 2020
Diesel fuel	2.76	kg CO_{2eq} L^{-1}	Pishgar-Komleh et al., 2012; Saldukaite et al., 2022; Šarauskis et al., 2019; Juknevičius et al., 2020
Propane	0.63	kg CO_{2eq} L^{-1}	Bos et al., 2014, Šarauskis et al., 2019
Herbicides	6.3	kg CO_{2eq} kg^{-1}	Lal, 2004, Pishgar-Komleh et al., 2012; Saldukaite et al., 2022; Juknevičius et al., 2020
Fungicides	3.9	kg CO_{2eq} kg^{-1}	Lal, 2004, Pishgar-Komleh et al., 2012, Saldukaite et al., 2022; Juknevičius et al., 2020
Insecticides	5.1	kg CO_{2eq} kg^{-1}	Lal, 2004, Pishgar-Komleh et al., 2012; Saldukaite et al., 2022; Juknevičius et al., 2020
Nitrogen	1.3	kg CO_{2eq} kg^{-1}	Lal, 2004, Pishgar-Komleh et al., 2012; Saldukaite et al., 2022; Juknevičius et al., 2020
Nitrogen	4.96	kg CO_{2eq} kg^{-1}	Kazlauskas et al., 2021
Phosphate	0.2	kg CO_{2eq} kg^{-1}	Lal, 2004, Pishgar-Komleh et al., 2012; Šarauskis et al., 2019; Juknevičius et al., 2020
P_2O_5	1.35	kg CO_{2eq} kg^{-1}	Kazlauskas et al., 2021
Potassium	0.15	kg CO_{2eq} kg^{-1}	Lal, 2004, Pishgar-Komleh et al., 2012; Šarauskis et al., 2019; Juknevičius et al., 2020
K_2O	0.58	kg CO_{2eq} kg^{-1}	Kazlauskas et al., 2021
Other micro fertilizers	4.5	kg CO_{2eq} kg^{-1}	Saldukaite et al., 2022
Sulphur	0.072	kg CO_{2eq} kg^{-1}	Saldukaite et al., 2022; Juknevičius et al., 2020
Biopreparation	4.2	kg CO_{2eq} kg^{-1}	Saldukaite et al., 2022; Juknevičius et al., 2020
Manure	0.126	kg CO_{2eq} kg^{-1}	Pishgar-Komleh et al., 2013; Šarauskis et al., 2019

High demand for mineral fertilizers causes high GHG emissions. Various studies are conducted in Lithuania, when a variable fertilizer rate is applied according to analyzes of the chemical properties of the soil. Kazlauskas et al. (2021) claim that lower spreads of fertilizers all over the field resulted in lower GHG emissions to the environment during the study period. Phosphorus and potassium variable rate fertilization application was estimated to reduce the GHG emissions by almost twice compared to fixed

rate fertilization. For the total amount of NPK fertilizers, 11.3% lower GHG emissions were obtained. At the end of the study, GHG emission reductions of 341.5 kg CO_2eq ha^{-1} or 3882.6 kg CO_2eq $Field^{-1}$ (22.4 ha) were determined.

What proportion of total GHG emissions are produced by fertilizers, pesticides, fuels, machinery, etc. costs in the cultivation of winter wheat can be seen in Fig.13.

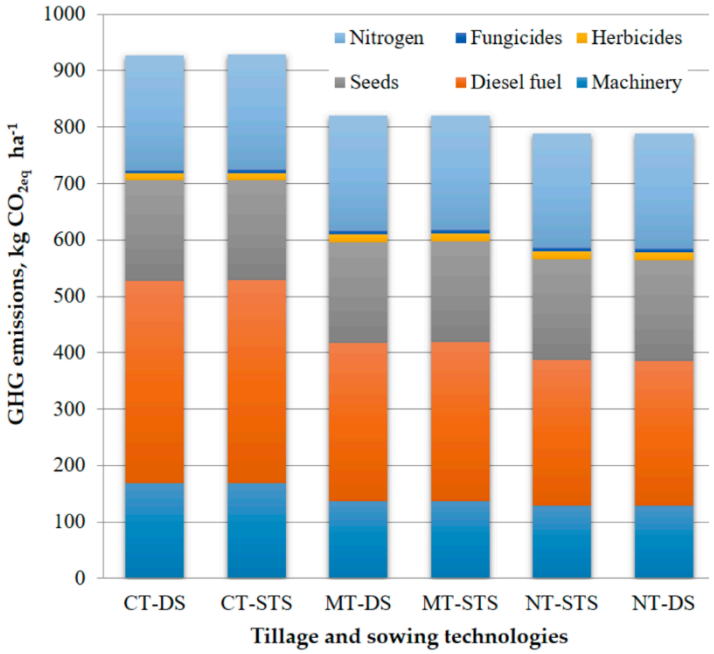

Figure 13. Contribution of different inputs in CO_2eq for winter wheat production (Saldukaitė-Sribikė et al., 2022)

In terms of greenhouse gas emissions (GHG), fertilizer use is the key factor which accounts for over 60% of total emissions. Compared to the control treatment (T3), with the use of biopreparations (T1 and T2) it is possible to decrease GHG emissions per one ton of winter wheat and winter oilseed rape yield produced by 10.3–27.7% and 7.0–19.3% respectively. Regardless of the crop type and the year, in treatment T1, where biopreparation was used, were the lowest GHG emissions per one hectare, 668.6–784.5 kg CO_2eq and 960.3 kg CO_2eq for winter wheat and winter oilseed rape, respectively (Juknevičius et al., 2020).

Because of the differences between the crop cultivation treatments and the crop yield, it is extremely important to assess the GHG emissions generated per single ton (1.0 Mg) of produce. The results of the environmental impact analysis show that in all years of the experiment, GHG emissions followed the same trend, i.e., the lowest emissions were recorded in treatment T1, where, due to the lower rate of fertilizer applied to winter wheat, emissions ranged from 108.7 to 149.1 kg CO_2eq Mg−1, while the highest emissions were recorded in T3 – 132.5–203.7 kg CO_2eq Mg−1. In terms of winter oilseed rape, 280.0, 320.1 and 343.4 kg CO_2eq Mg−1 were recorded in treatments T1, T2 and T3, respectively. The results of GHG emissions assessment according to the different agricultural inputs and treatments are presented in Table 7 (Juknevičius et al., 2020).

Data on GHG emissions from harvesting, spraying, fertilizing and other technological operations depend on the type of crop, the amount of fertilizer, pesticides and other chemicals used, the technical parameters of the machinery, etc. The most polluting operations are the harvesting of maize for silage and the harvesting of fodder by combine harvesters (Lal, 2004).

In meta-analysis study (Shakoor et al., 2021) systematically compared the GHGs emissions of the soil under different animal manures, the quantity of manure, climate zone, soil pH, water filled pore space (WFPS), soil texture, crop type, and crop duration. The main objectives of this study were to address

the following questions: 1) Do the application and amount of different animal manures affect soil GHGs emissions as compared to control and/or no fertilizer? 2) Which GHG more affected by the application of animal manure and manure rate? 3) Do crop duration and crop species important factors for regulating the GHGs emissions? and finally, 4) How do soil attributes and different climate zones affect soil GHGs emissions? In total, 48 peer-reviewed publications on manure application were selected published from 1989 to 2019.

Table 7. GHG emissions in different winter wheat and winter oilseed rape cultivation treatments (Juknevičius et al., 2020)

Greenhouse Gas Emissions kg CO_2eq Mg^{-1}									
Year	**2017**			**2018**			**2019**		
Treatment	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**
Fuel	33.22	32.47	40.00	59.36	58.82	63.22	23.92	23.35	26.04
Agricultural machinery	13.49	13.18	16.24	26.72	26.48	28.46	12.91	12.60	14.06
Seed Wheat	10.65	10.41	12.83	-	-	-	9.10	8.89	9.91
Seed OSR	-	-	-	0.64	0.63	0.68	-	-	-
Herbicides	0.84	0.82	1.01	4.22	4.18	4.50	0.72	0.70	0.78
Insecticides	0.04	0.04	0.04	0.97	0.96	1.03	0.03	0.03	0.03
Fungicides	1.50	1.47	1.81	3.86	3.83	4.11	2.07	2.02	2.26
Biopreparations	1.88	0.40	0.00	2.88	0.62	0.00	1.61	0.34	0.00
Nitrogen	35.53	43.41	53.49	64.98	80.48	86.51	34.14	41.66	46.46
Phosphate	1.34	1.64	2.02	2.05	2.54	2.73	1.43	1.75	1.95
Potassium	1.32	1.62	1.99	2.03	2.51	2.70	0.00	0.00	0.00
Sulphur	49.33	60.26	74.25	112.27	139.06	149.47	22.78	27.80	31.00
Total fertilizers	89.40	107.32	131.74	184.21	225.22	241.40	59.96	71.55	79.41
Total input	**149.14**	**165.71**	**203.68**	**279.98**	**320.12**	**343.40**	**108.71**	**119.14**	**132.48**

Of the total, 324 and 242 paired-wise observations were selected for manure type and manure rate, respectively. Three types of manure (pig, cattle and poultry) and three levels of manure rate (120, 320, and >320 kg N ha^{-1}) were chosen to check the effect on GHGs emissions. The application of different manure types and rates had significantly positive effects on CO_2, CH_4, and N_2O emissions.

Based on meta-analysis results, the overall effect sizes of manure type and manure rate on CO_2, CH_4, and N_2O emissions were significantly greater than zero (Fig. 14), but slightly negative effects on CO_2 emission related to manure rate was also observed (Fig. 14a (i)), showing that application of different manure type and manure rate considerably increased CO_2, CH_4 as well as N_2O emissions from the agricultural soil as compared to controls. The manure and mineral nitrogen application rates were directly proportional to the GHGs emissions because C, N, phosphorus (P) and potash (K) contents were increased accordingly in the soil. Evidence presented in this meta-analysis shows that the application of animal manure and N-mineral fertilizer significantly increased CO_2, CH_4 and N_2O emission as compared to control treatment from soils. The effect of animal manure and N-mineral fertilizer on CO_2, CH_4 and N_2O emissions were considerably depended on soil attributes like soil pH, WFPS, soil

texture, crop types, and climate zones, indicating that these factors need to be fully considered to optimize the fertilization strategies to reduce the emissions of GHGs.

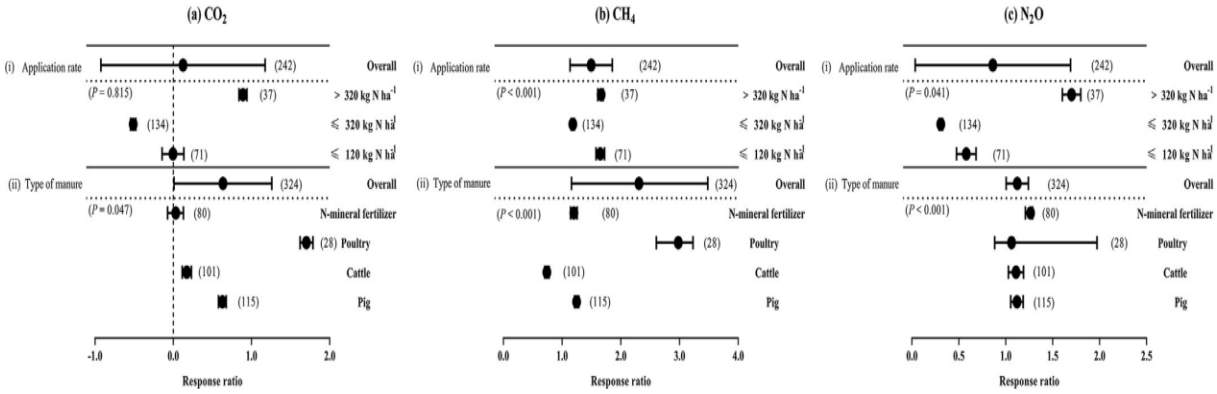

Figure 14. Impact of (i) animal manure and mineral fertilizer application rate (kg N ha^{-1}) and (ii) manure type on (a) CO_2, (b) CH_4 and (c) N_2O emissions from agricultural soils. Symbols represent mean effect sizes with 95% confidence intervals. Sample sizes are presented in parentheses and the P values are shown in the panel.

Effect sizes of soil texture on CO_2, CH_4 and N_2O emissions after manure application are shown in Fig. 15. According to meta-analysis dataset, all soils were classified into different textural classes e.g. clay, clay loam, loam, sandy loam, sandy, sandy clay loam, silt loam, slit clay and silty clay loam. The overall effect sizes of soil texture on CO_2, CH_4 and N_2O emissions were significantly positive, revealing that soil texture had a very strong effect on GHGs emissions from the terrestrial environment. All textural classes showed significantly positive response to CO_2 emission and maximum emission of CO_2 was observed in silt loam soil (Fig. 15a). On the other hand, all textural classes also gave a considerably positive response to CH_4 and N_2O (except loamy soil) emissions. The highest concentration of CH_4 and N_2O emissions were found in silty clay loam and sandy loam soils, respectively (Fig. 15b and c).

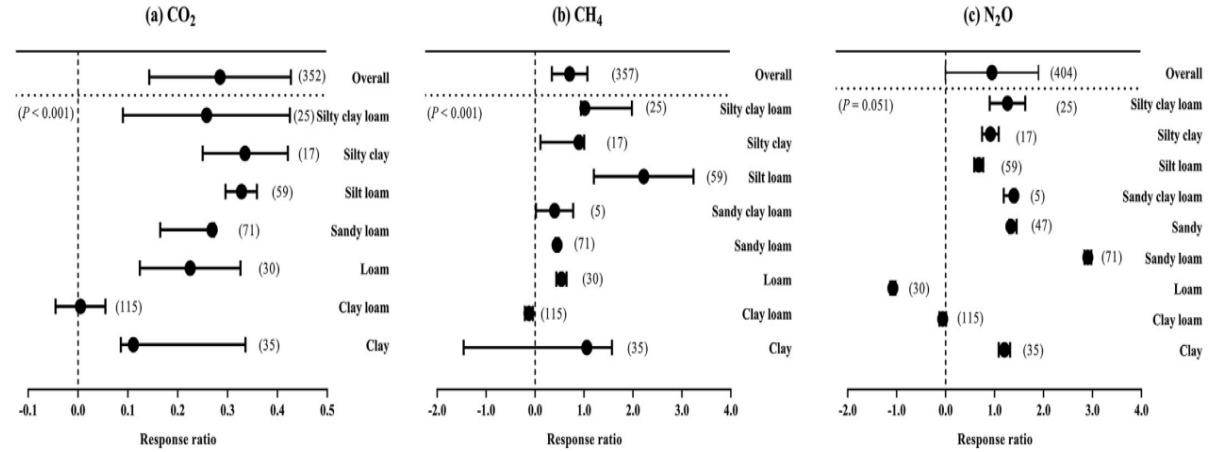

Figure 15. CO_2, (b) CH_4 and (c) N_2O emissions from agricultural soils affected by soil textural class. Symbols represent mean effect sizes with 95% confidence intervals. Sample sizes are presented in parentheses and the P values are shown in the panel.

The crop species and study duration also played an important role in the differences in GHGs emissions (Huang et al., 2018). Different crop species like barley, grassland, maize, rice, soybean, sweet corn, wheat, and the fallow period between crops were chosen for meta-analysis, while, the study duration was categorized as 320 days, 321–725 days, > 725 days (Fig. 16). Based on the results of meta-

analysis, the overall effect size for both crop duration and type was significantly greater than zero, presenting that both parameters had positive effects on CO_2, CH_4 and N_2O emissions. Crop duration is also a very important factor in controlling GHGs emissions. Crops that having >321 days had more CO_2 and N_2O emissions (Fig. 16a (i) and 3c (i)). While, a higher concentration of CH_4 was observed when crop duration was 320 days (Fig. 3b (i)). Meta-analysis findings were similar to previous research study (Leytem et al., 2019). According to meta-analysis, barley produced maximum emission of CO_2 (Fig. 3a (ii)) which was similar to Gan et al. (2012) research study. Smith et al. (2019) also studied and reported that barley, which normally requires less manure and/or synthetic fertilizer than other cereals crops, have greater CO_2 emissions per unit production.

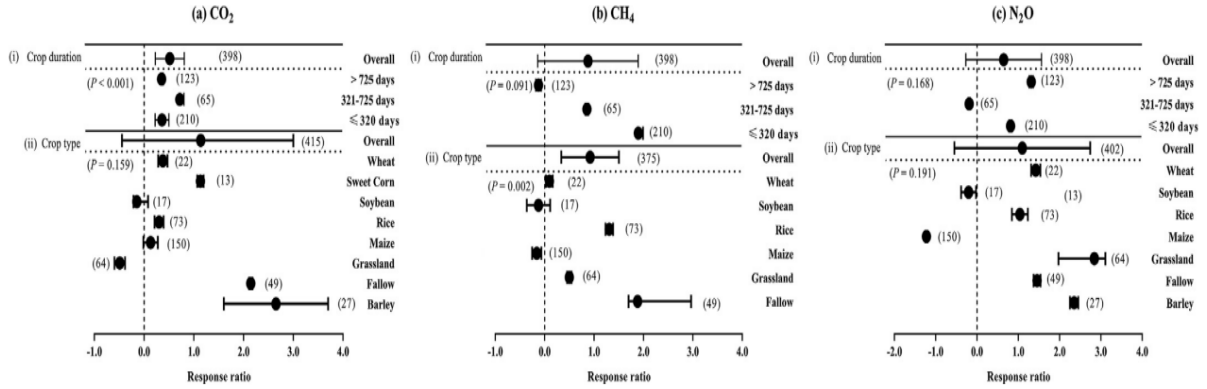

Figure 16. Influence of (i) crop duration (days) and (ii) crop type on (a) CO2, (b) CH4 and (c) N2O emissions from agricultural soils. Symbols represent mean effect sizes with 95% confidence intervals. Sample sizes are presented in parentheses and the P values are shown in the panel.

Climate zones had shown significantly positive effects on CO_2, CH_4, and N_2O emissions because the overall effect sizes of climate zones were significantly great than 0. According to meta-analysis results, tropical and sub-tropical regions emitted more CO_2 and N_2O but on the other hand, the higher concentration of CH_4 was found in cool temperate zone (Fig. 17). Van der Werf et al. (2009) found that the maximum concentration of CO_2 is emitted from the tropical zone.

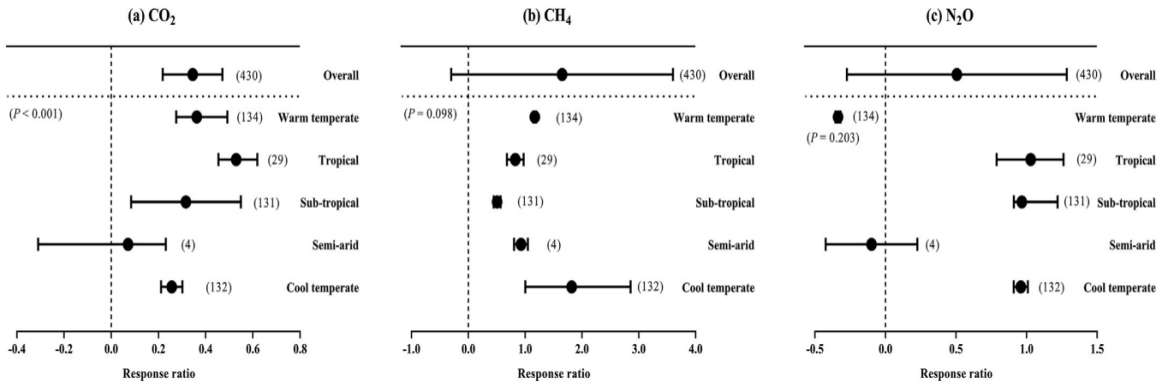

Figure 17. Effect of climate zone on (a) CO_2, (b) CH_4 and (c) N_2O emissions from agricultural soils. Symbols represent mean effect sizes with 95% confidence intervals. Sample sizes are presented in parentheses and the P values are shown in the panel.

Different research studies found that higher N_2O emission emitted from the warm temperate zone (Luo et al., 2013) due to microbial activities (Pärn et al., 2018) but this meta-analysis study revealed that sub-tropical and cool temperate zones produced higher N_2O concentration than other regions (Fig. 17c). Welti et al. (2017) also found the higher N_2O emissions from agricultural soils under sub-tropical zones. The sensitivity of climatic conditions of N_2O emission is not well-known, so, it is difficult to project how manure application and climatic conditions will impact the N_2O emission (Griffis et al., 2017). Another

study also proposed that maximum CH_4 emissions are emitted by paddy fields in snowy temperate regions (Naser et al., 2007).

2.4 GHG emission in animal husbandry

Animal husbandry is an important source of air pollution, and a lot of research and innovation has been done to reduce air pollution. Therefore, it is very important to evaluate these innovations in the ongoing monitoring of GHG emissions.

After summarizing the results of scientific research and good experience, the rules for the technological design of buildings in Rules for the technological design of agriculture for all animals were updated, providing recommendations on how to reduce the amount of gas emissions in animal husbandry. During the implementation of projects for the dissemination of scientific knowledge, educational activities about sustainable animal husbandry technologies and measures to increase sustainability are very actively carried out in the country, many field days and seminars are organized, which explain how to implement measures to reduce air pollution.

In one of the projects, a methodology and program for GHG calculation at farm level was developed according to IPCC guidelines. Calculation or experimental determination of methane, nitrous oxide gas emissions coefficients, livestock keeping conditions must be evaluated, modern manure management methods are applied technologies (manure removal from the barn, manure pits, manure incorporation into the soil), applied bio means to optimize fermentation and microbiological processes, temperature change. Agricultural soils could begin to accumulate organic carbon in larger quantities by applying measures - increasing biomass production in crops through cover crops, crop rotation, agroforestry; protecting soil organic carbon during tillage: after reducing plowing; by improving the soil structure; by processing and incorporating organic carbon, using organic fertilizers; leaving straw and other plant remains; using compost and anaerobic fermentation as a means of soil improvement; by incorporating charcoal; nurturing grasslands and wetlands, including grazing livestock, landscaping in agriculture (buffer belts to protect water bodies, control erosion and foster biological diversity, management of wetlands, bogs and peatlands). During the R&D project, after analyzing all the factors that form emissions at the farm level and correctly reflects sustainable economic actions that ensure circularity and sustainable resources principles of use, a Farm GHG calculation tool was created, with the help of which they will be able to to determine the sources of emissions of technologies and tools applied on the farm in accordance with the IPCC methodology (Ministry of Agriculture…, 2022).

The Lithuanian livestock sector annually emits about 1800 kt of GHG CO_2 eq. (this accounts for about 42% of emissions in the agricultural sector or about 9.0% of the total amount of GHG in Lithuania).

Main GHGs in animal husbandry:

- methane gas (CH_4). They mostly evaporate from digestion processes (this gas accounts for about 78% of the GHG emissions in animal husbandry CO_2 eq.) and from manure management systems (this gas accounts for about 12% of the GHG emissions in animal husbandry CO_2 eq.);
- nitrous oxide (N_2O). They mostly evaporate from manure management systems (this gas accounts for about 10% of GHG emissions in animal husbandry in CO_2 eq.).

After assessing the sources of gas emissions and reducing the impact of animal husbandry on climate change, research in Lithuania is carried out in the following directions:

1. reduction of methane gas emissions during enteric fermentation (changes and optimization of feed rations, use of new feed additives, optimization of animal housing conditions and feed preparation and feeding systems, etc.);
2. reduction of methane gas emissions from manure management systems (optimized feed rations, controlled anaerobic process, the most efficient method is applied - to collect methane gas, etc.);
3. nitrous oxide, etc. reduction of gas emissions from manure management systems (nitrogen losses from manure etc. are reduced).

I. Most scientific research is conducted to increase the sustainability of cattle farming. Scientists are looking for solutions to reduce the amount of methane released during enteric fermentation in ruminants. One of the most sustainable strategies for methane reduction is applied - manipulation of cattle nutrition by adding feed additives with methane-inhibitory potential to the diet. Recently, various species of red, brown and green seaweeds have been extensively researched due to the biologically active substance in their composition - bromoform. Different types of seaweed not only have a positive effect on animal productivity (milk composition and quantity), but also reduce the amount of methane released during enteric fermentation by cattle by up to 80%.Gas emissions are reduced by using appropriate genetics and innovative feeding solutions (by optimizing the diet according to the amount of protein, fat, and fiber).
   By improving the conditions of keeping animals, increasing the efficiency of work processes and the productivity of animals, the emission of methane gas to produce a unit of production decreases. In order to optimize the well-being of animals, many different projects have been carried out, a lot of research has been carried out, algorithms have been developed for optimizing the microclimate of barns, tools have been created to create an optimal microclimate in winter and summer during hot weather, barn automation processes are studied and optimized, computer programs are created for the control of technological processes and livestock herd management, technological sensors working on the principle of laser spectroscopy (used in robotic barns) are being developed for quality control of processes. In barns, robotic systems are installed that can perform all tasks (cow milking, fodder preparation and feeding and watering, manure management, microclimate management, etc.) more accurately and better than humans, and automated livestock herd management systems are installed (Antanaitis et al., 2022; Bagdonienė et al., 2014; Baležentienė et al., 2011; Bleizgys et al., 2013; 2014; 2017a; 2017b; 2021; 2022; 2023a; 2023b).
II. The most efficient way to reduce methane gas emissions from manure is by collecting the gas released from manure. Many studies have been carried out and are being carried out in order to increase the concentration of methane gas in biogas, by increasing the yield of biogas and increasing the efficiency of biogas production, the potential of methane formation from various types of manure has been determined. These goals are achieved by optimizing the composition of the substrate for biogas production, reducing energy consumption for the anaerobic process, using various compositions of microorganisms for the substrate. Innovative biogas production technologies are implemented in medium and large livestock farms where liquid or solid manure is stored (Juškienė et al., 2023; Knoknerienė et al. 2023; Lekavičius et al., 2021; Marašinskienė et al., 2022; Rubežius et al., 2020a; 2020b; Žalys et al., 2023).
III. In order to reduce nitrogen losses from manure, measures have been developed to reduce ammonia emissions from manure. Methods have been developed to reduce air pollution from them by applying technological measures in barns: by reducing the area of the manure surface and the intensity of mixing, the humidity of the manure surface, optimizing the ambient temperature and air flows over the manure (by controlling the gas concentration gradient above the manure), directing the polluted air to biofilters (efficiency up to 90 percent). New multifunctional compositions of microorganisms have been created, which effectively reduce gas emissions in all technological stages of manure management: in barns, manure pits, when manure is incorporated into the soil. Automated systems for inoculating probiotics into manure. New compositions of bioactive manure coatings have been developed that optimize crust formation on the manure surface and effectively reduce gas evaporation. Manure acidification technologies are being researched and implemented (efficiency up to 50%). Cold and thermal manure separation processes are optimized: liquid and solid fractions are separated in manure. Fractionation of manure changes the composition of manure in individual fractions, the surface area of manure and reduces the amount of gas emissions. The innovations created are applied and effectively implemented in many Lithuanian farms.

Research has determined the amount of nitrogen released in different groups of animals and calculated emissions of greenhouse gases (CH_4 and N_2O) (emission factors) in individual manure management systems (Juškienė et al., 2020; Kalvaitis et. al. 2022; Knoknerienė et al., 2023; Lekavičius et al., 2021; Marašinskienė et al., 2022; Mažeikienė et al., 2022; Naujokienė et al., 2021; 2022; Petokaitis et al., 2017; Velėniūtė et al., 2020).

In one of the projects, a methodology and program for GHG calculation at farm level was developed according to IPCC guidelines. Calculation or experimental determination of methane, nitrous oxide gas emissions coefficients, livestock keeping conditions must be evaluated, modern manure management methods are applied technologies (manure removal from the barn, manure pits, manure incorporation into the soil), applied bio means to optimize fermentation and microbiological processes, temperature change. Agricultural soils could begin to accumulate organic carbon in larger quantities by applying measures - increasing biomass production in crops through cover crops, crop rotation, agroforestry; protecting soil organic carbon during tillage: after reducing plowing; by improving the soil structure; by processing and incorporating organic carbon, using organic fertilizers; leaving straw and other plant remains; using compost and anaerobic fermentation as a means of soil improvement; by incorporating charcoal; nurturing grasslands and wetlands, including grazing livestock, landscaping in agriculture (buffer belts to protect water bodies, control erosion and foster biological diversity, management of wetlands, bogs and peatlands). During the R&D project, after analyzing all the factors that form emissions at the farm level and correctly reflects sustainable economic actions that ensure circularity and sustainable resources principles of use, a Farm GHG calculation tool was created, with the help of which they will be able to to determine the sources of emissions of technologies and tools applied on the farm in accordance with the IPCC methodology (Ministry of Agriculture…, 2022).

After summarizing the results of scientific research and good experience, the rules for the technological design of buildings in Rules for the technological design of agriculture for all animals were updated, providing recommendations on how to reduce the amount of gas emissions in animal husbandry. During the implementation of projects for the dissemination of scientific knowledge, educational activities about sustainable animal husbandry technologies and measures to increase sustainability are very actively carried out in the country, many field days and seminars are organized, which explain how to implement measures to reduce air pollution.

Animal husbandry is an important source of air pollution, and a lot of research and innovation has been done to reduce air pollution. Therefore, it is very important to evaluate these innovations in the ongoing monitoring of GHG emissions.

2.5 Experiences of other countries using technologies and instruments reducing GHG and increasing CO_2 absorption

Data on overall pollution in agriculture and other sectors are available in the Eurostat database (https://ec.europa.eu/eurostat). However, these data mainly rely on energy consumption quantities, making them somewhat imprecise as agriculture is a complex sector that involves not only GHG pollution related to energy use or animal husbandry but also the absorption of these pollutants related to crop cultivation. Therefore, an accurate assessment of GHG pollution in agriculture remains a significant challenge. The Intergovernmental Panel on Climate Change (IPCC) has developed guidelines and a consistent and standard system for calculating national GHG emissions. The key principles established in the IPCC guidelines for GHG inventories are consistency, transparency, accuracy, comparability, and completeness (Rosenstock et al., 2019).

IPCC guidelines for GHG emission assessment have long been employed in scientific literature, including the agricultural sector. Over a decade ago, researchers such as Crosson et al. (2011) produced a literature review presenting studies that utilized IPCC guidelines to estimate GHG emissions in agriculture, especially the livestock sector, and explored key factors for reducing GHG emissions. However, scholars (Hedayati et al., 2019; O'Brien et al., 2014; Pryor et al., 2017) have pointed out that

while IPCC methodologies are suitable for national-level accounting purposes, they lack the holistic approach and farm-level solutions needed for the analysis of all agricultural systems.
In recent years, various scholars (O'brien et al., 2012, 2014; Pryor et al., 2017; Hedayati et al., 2019) have analyzed differences between IPCC methodology and other calculation methods like life cycle assessment or more complex methods based on carbon and nitrogen cycles. They found that life cycle analysis is often applied due to its accuracy and detailed information, making it more suitable for assessing the impact of changes in agricultural management on GHG emissions. However, the collection of data required for life cycle analysis, even when collecting individual farm data, is quite challenging.
Furthermore, researchers propose reforming or expanding the accounting methodology based on IPCC guidelines to include more components and data related to various climate change mitigation measures applied and to the use of inputs (fertilizers, pesticides, etc.) in agriculture (O'brien et al., 2014; Khalil et al., 2020). Therefore, the application of IPCC guidelines suggests a tiered approach for a more accurate GHG accounting. IPCC guidelines present mainly two tiers, though the scientific literature suggests including a third tier for assessing GHG emissions (Bell et al., 2014; Peter et al., 2016; Peter et al., 2017; Paul et al., 2018).

2.6 Review and evaluation of existing or developing platforms or calculators

According to (Peter et al., 2017) the wide analysis was made focused on the calculator's goal and scope, methodology for GHG emission accounting in energy crop cultivation, management practices, and the ability to model crop rotations (Fig. 18). Among the 44 environmental assessment calculators (Table 8) for agricultural products, 18 were identified as capable of assessing GHG emissions from energy crop cultivation. These calculators vary in their goal and scope, accounting for farming operations related to crop management, making it challenging to compare and interpret results from CFP assessments.

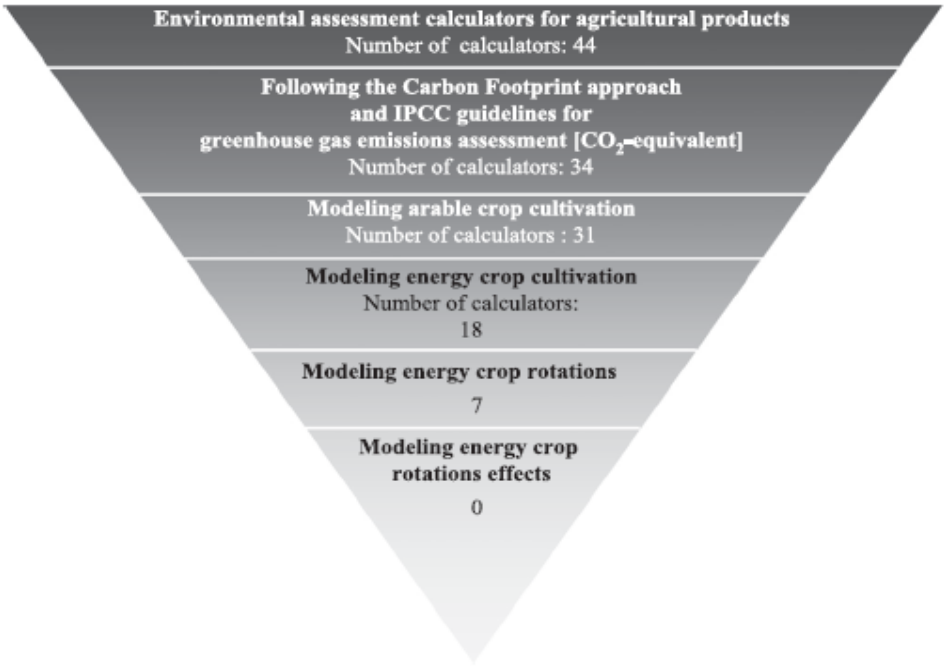

Fig. 18. Selection process for GHG emission calculators for energy crop cultivation (Peter et al., 2017)

All 18 examined calculators have the capability to compute GHG emissions from "cradle to farm gate" and these outcomes can be incorporated into subsequent Carbon Footprint (CFP) assessments of bioenergy production chains. The established system boundary influences the processes, activities, and sources considered in each calculator. System boundaries in CFP studies for agricultural production systems exhibit significant variability both within and among the same production chains. Using different calculators can lead to notable disparities in GHG emission results from the same dataset of a bioenergy production chain. The findings highlight the critical importance of the farming processes integrated into the calculator, the chosen calculation pathway, allocation method, and whether the entire cropping cycle (e.g., perennial crops) or only the crop is included (Peter et al., 2017).

Table 8. Overview of 44 environmental assessment calculators for agricultural products (in bold are the 18 calculators suitable for energy crop production)(Peter et al., 2017)

Calculator name	Interface	Method	Indicator GHG [CO_2-Eq]	Free software	Target user groups	More information
ACCT	Software	LCA + CFP	+		Scientists, farmers	http://www.agriclimatechange.eu/index.php?option=com_content&view=article&id=55&Itemid=81&lang=en
Agri-LCI models	Excel-based	LCA	+	+	None specified	http://www.cranfield.ac.uk/about/people-and-resources/schools-and-departments/school-of-applied-sciences/groups-institutes-and-centres/cwsi-software/CWSI-AgriLCA-download.html?ref=161050
ALU	Software	Modeling soil-plant-atmosphere system	+	+	Scientists	http://www.nrel.colostate.edu/projects/ALUsoftware/software_description.html
AMBITEC-AGRO	Excel-based	EIA	+		Scientists	(http://bs.sede.embrapa.br/2011/ambitec.html)
APOIA-Novo Rural	Software	EIA	+		Scientists	
BALANCE	Software	LCA	+		Scientists	http://www.ier.uni-stuttgart.de /forschung/modmeth/balance/index.html
BIOENERGIEDAT	Web-based (database)	LCA	+	+	Policymakers, companies	http://www.bioenergiedat.de
BioGrace	Excel-based	LCA	+	+	Farmers, companies	http://www.biograce.net/content/ghgcalculationtools/recognisedtool/
Calm	Web-based	CFP	+	+	Farmers	http://www.calm.cla.org.uk/
CAPRI	Software	LCA	+		Policymakers	http://www.capri-model.org
CFF	Web-based	LCA	+	+	Farmers	http://www.cffcarboncalculator.org.uk/
COMET FARM	Web-based	CFP	+	+	Farmers	https://www.cometvr.colostate.edu
Calculator name	**Interface**	**Method**	**Indicator GHG [CO_2-Eq]**	**Free software**	**Target user groups**	**More information**
CFT	Excel-based	LCA	+	+	Farmers, policymakers, companies	http://www.coolfarmtool.org/CftExcel
C-Plan	Web-based	CFP	+	+	Farmers, companies	http://www.see360.org.uk/calculator.html

CropSyst	Software	Modeling soil-plant-atmosphere system	+	+	Scientists	http://www.bsyse.wsu.edu/CS_Suite/CropSyst/index.html
DNDC Calculator	Software	Modeling soil-plant-atmosphere system	+	+	None specified	http://www.dndc.sr.unh.edu/
EMA	Software	Ecopoint system			Farmers	http://sitem.herts.ac.uk/aeru/ema/old/index.htm
Euphorus	Excel-based	LCA	+	+	Farmers	http://www.wageningenur.nl/en/Research-Results/Projects-and-programmes/Euphoros-1.htm
EX-ACT	Excel-based	Carbon balance	+	+	Scientists	http://www.fao.org/tc/exact/ex-act-home/en/
Farm Enterprising GHG Calculator	Web-based	CFP	+	+	Farmers	http://external-apps.qut.edu.au/ife/feggec/
Farm GAS	Web-based	CFP	+	+	Farmers, companies	http://calculator.farminstitute.org.au
Farm GHG	Software	LCA	+		Farmers	
Fieldprint Calculator	Web-based	CFP	+	+	Farmers	http://www.fieldtomarket.org/calculator.php
FSGGEC	Web-based	CFP	+	+	Farmers	http://surf.kbs.msu.edu/
GaBi	Software	LCA	+		Companies	http://www.gabi-software.com
GAS-EM	Excel-based	LCA	+		Policymakers	
Calculator name	**Interface**	**Method**	**Indicator GHG [CO_2-Eq]**	**Free software**	**Target user groups**	**More information**
GEMIS	Software	LCA	+	+	Companies, policymakers	http://www.iinas.org/news-de.html
Greenhouse in Agriculture tools; Grains Greenhouse Accounting Framework V6	Excel-based	CFP	+	+	Farmers, companies, policymakers	http://www.greenhouse.unimelb.edu.au/Tools.htm
HGCA 1	Excel-based	LCA + CFP	+	+	Farmers	http://www.hgca.com/tools/biofuel-greenhouse-gas-calculator.aspx

HGCA 2	Excel-based	CFP	+	+	Farmers	http://www.hgca.com/tools/carbon-footprinting-decision-support-tool.aspx
Holos	Software	CFP	+	+	Farmers	http://www.agr.gc.ca/eng/science-and-innovation/science-publications-and-resources/holos/?id=1349181297838
IFSC	Excel-based	CFP	+	+	Farmers	https://ideals.illinois.edu/handle/2142/13458
IMPACCT	Software	LCA, CFP	+	+	Farmers	http://sitem.herts.ac.uk/aeru/impacct/software.htm
INDIGO	Software	Own approach			Farmers, scientists	
KUL	Software	Own approach			Farmers, scientists	
Lincoln Farm Carbon Calculator	Web-based	LCA + CFP	+	+	Farmers	http://www2.lincoln.ac.nz/carboncalculator/
openLCA	Software	LCA	+	+	Scientists, policymakers, companies	http://www.openlca.org
ProBas	Software	LCA	+	+	Policymakers, companies	http://www.probas.umweltbundesamt.de/php/themen.php
Repro	Software	Farm accounting tool	+		Scientists, farmers	
Calculator name	**Interface**	**Method**	**Indicator GHG [CO_2-Eq]**	**Free software**	**Target user groups**	**More information**
SALCA	Software	LCA	+		Companies, farmers, policy-makers, scientists	http://www.agroscope.admin.ch/oekobilanzen/01199/index.html?lang=de
SimaPro	Software	LCA	+		Companies, scientists, policy-makers	http://www.pre-sustainability.com/software
Solagro	Web-based	LCA	+	+	Farmers	https://carbone.solagro.org/current/modules/registration.php
TRACI	Software	LCA	+		Companies, scientists, Policy-makers	http://www.epa.gov/nrmrl/std/traci/traci.html
Umberto	Software	LCA	+		Companies	http://www.umberto.de

2.7 Overview of applied technological solutions for monitoring GHG emissions in AFOLU sector

Monitoring greenhouse gas emissions in the Agriculture, Forestry, and Other Land Use sectors is essential for several reasons. Firstly, it allows for a comprehensive understanding of emission sources, particularly from activities like deforestation, agriculture, and land-use changes. This monitoring is essential to assess carbon stocks in forests, soil, and vegetation, providing insights into the effectiveness of different land-use practices in mitigating climate change (Nabuurs, et al., 2022).
Accurate monitoring is vital for the development and implementation of effective climate change mitigation strategies. This includes efforts to reduce deforestation, promote afforestation, implement sustainable agricultural practices, and enhance carbon sequestration through improved land management. Moreover, many countries are obligated to report their GHG emissions and removals, including those from the AFOLU sector, as part of international agreements like the Paris Agreement (*Monitoring, Measurement and Verification of Greenhouse Gas Emissions II: The Role of Federal and Academic Research and Monitoring Programs | NIST*, n.d.).
The data generated from monitoring efforts inform policymakers, enabling them to make informed decisions and design policies that incentivize sustainable land-use practices. It also plays a crucial role in evaluating the impact of land-use changes on the overall carbon balance and climate system. Sustainable agriculture practices, optimized resource use, and enhanced agricultural efficiency can be identified through monitoring, contributing to the reduction of emissions from activities such as fertilizer use, enteric fermentation from livestock, and crops cultivation (OECD, 2013).
Monitoring in the AFOLU sector is integral to the integrity of carbon markets, especially in projects related to carbon offsetting. Verification of emission reductions ensures trust in offsetting mechanisms. Additionally, logging and deforestation issues, supports efforts to combat illegal logging, and contributes to biodiversity conservation. Understanding current and future GHG emissions in the AFOLU sector is not only vital for global climate change mitigation but also for adapting to climate change impacts. This includes developing strategies to address changing precipitation patterns, temperature extremes, and other climate-related challenges. In summary, monitoring GHG emissions in the AFOLU sector is a linchpin for sustainable land-use management, contributing to global climate goals and local resilience efforts (Nabuurs, et al., 2022).

Key applied technological solutions

1. **Remote Sensing and Satellite Technology**: Satellite imagery and remote sensing technologies are extensively used for monitoring land use changes, such as deforestation, afforestation, and reforestation. They provide large-scale, real-time data on biomass, land cover changes, and can be used to estimate CO2 emissions and removals (Harris et al., 2021).
2. **Drones and Aerial Photography:** Unmanned Aerial Vehicles (UAVs) or drones equipped with sensors and cameras can capture high-resolution images of agricultural lands and forests. They are used for detailed monitoring of land use changes, crop health, and can assist in estimating emissions from specific areas (Burgués et al., 2022).
3. **GIS and Spatial Analysis**: Geographic Information Systems (GIS) are crucial for managing and analyzing spatial data collected through remote sensing and other sources. They allow for the mapping of land-use changes, carbon stock assessments, and help in modeling and predicting GHG emissions (Smith et al. 2014; Jia et al. 2019).
4. **Livestock Emission Monitoring**: Technologies like laser methane detectors and portable gas analyzers can be used to directly measure methane emissions from livestock. Automated feeding stations can also monitor feed intake and emissions at an individual animal level (Sorg, 2021).
5. **Soil Carbon Measurement**: Advanced techniques like spectroscopy and laser-induced breakdown spectroscopy (LIBS) are used for rapid soil carbon measurements. These methods

help in assessing soil carbon stocks and changes due to land use, which are vital for calculating GHG emissions from soils (Izaurralde et al., 2013).

6. **Data Management and Reporting Software**: Specialized software platforms are used for collecting, managing, and reporting emission data. These platforms can integrate data from various sources, apply emission factors, and assist in compliance reporting under national and international frameworks (*Carbon Ledger: Track Greenhouse Gas Emissions Data: PwC*, n.d.).
7. **Internet of Things (IoT) and Sensors**: IoT devices and sensors can be deployed in agricultural and forested areas to collect various data points such as temperature, humidity, soil composition, and even the health of vegetation. This data can be used to model GHG emissions more accurately (Jaliyagoda et al., 2023).
8. **Mobile Applications**: Mobile apps enable farmers and land managers to record practices, changes in land use, and other relevant data. This information can feed into larger databases to track and estimate GHG emissions at local, regional, or national levels (*COMET-Global: Whole-Farm GHG Estimation and Environmental Diagnostics Platform - COLORADO STATE UNIVERSITY*, n.d.; *Transform the Farming Techniques with Mobile Application for Agriculture*, n.d.).
9. **Carbon Modeling Tools**: Various computer models and software tools are available to estimate and predict GHG emissions based on different scenarios of land use and management practices. These models are crucial for planning and implementing emission reduction strategies (Sohl et al., 2012; *USGS LandCarbon Visualization Tools | Climate Change Resource Center*, n.d.).

International practices applied for GHG calculations in AFOLU sector

International practices for calculating and assessing GHG emissions in the AFOLU sector are guided by principles and methodologies established by global organizations and agreements. These practices ensure consistency, transparency, and accuracy in GHG accounting across different countries and regions. Key elements of these practices include:

1. **Intergovernmental Panel on Climate Change (IPCC) Guidelines**: The IPCC provides comprehensive methodologies for estimating GHG emissions and removals in the AFOLU sector. These guidelines offer tiered approaches – Tier 1 (basic), Tier 2 (intermediate), and Tier 3 (advanced) – depending on the country's capacity and the availability of data. They cover various sources of emissions, including enteric fermentation in livestock, rice cultivation, biomass burning, and changes in forest and other woody biomass stocks (Nabuurs, et al., 2022).
2. **United Nations Framework Convention on Climate Change (UNFCCC) Reporting**: Countries that are parties to the UNFCCC are required to submit national GHG inventories, including emissions from the AFOLU sector. Developed countries provide annual inventories, while developing countries may do so less frequently. These inventories are crucial for tracking progress towards international climate goals, such as those outlined in the Paris Agreement. The submissions are in two parts: the Common Reporting Format (CRF) tables containing quantitative information and the National Inventory Report (NIR) providing detailed information on inventory methodologies, data sources, institutional arrangements, quality assurance procedures, and any recalculations or changes compared to previous inventories (UNFCCC. (n.d.)).
3. **Use of National Greenhouse Gas Inventories**: Countries develop their national GHG inventories based on the IPCC guidelines. These inventories are tailored to the specific conditions of each country, taking into account national land use patterns, agricultural practices, and forest management practices (Nabuurs, et al., 2022).
4. **Land Use, Land-Use Change, and Forestry (LULUCF) Accounting**: LULUCF is a key category within the GHG inventories that focuses on land use and its change, including forestry and other

land use. This accounting includes both emissions and removals of GHGs resulting from direct human-induced land use changes (Greenhalgh et al., 2006).

5. **Activity Data and Emission Factors**: GHG estimations are based on activity data (e.g., area of land deforested, amount of fertilizer used) and emission factors (e.g., emissions per unit of activity). Countries may use default emission factors provided by the IPCC or develop their own, based on local data (Nabuurs, et al., 2022).
6. **Remote Sensing and Ground-Truthing**: Satellite imagery and remote sensing are increasingly used for land monitoring, providing large-scale and updated data. Ground-truthing, or verifying remote sensing data with on-site measurements, is essential for accuracy (*Ground Truthing: Verify Remotely Collected Data - GIS Geography*, n.d.).
7. **Verification and Peer Review**: International practices emphasize the importance of verification and peer review of GHG inventories. This process ensures the reliability and transparency of the reported data (United Nations Framework Convention on Climate Change (UNFCCC), 2017)) .
8. **Transparency Framework under the Paris Agreement**: The Enhanced Transparency Framework (ETF) under the Paris Agreement establishes more robust and harmonized reporting requirements, which include reporting on GHG emissions and actions in the AFOLU sector (UNCCS, 2022).

2.8 International practices applied in other countries of GHG platforms or calculators

- **GHG Protocol Tools**: The GHG Protocol offers a suite of tools that are widely used globally. These include cross-sector tools applicable to various industries, country-specific tools tailored for developing countries, and sector-specific tools. Additionally, there are tools specifically designed for countries and cities to track progress towards climate goals. The GHG Protocol's tools are based on best-practice methods and have been extensively tested by industry experts (GHG protocol, n.d.).
- **European Commission's GHG Calculation Tool**: In Europe, the European Commission has developed a greenhouse gas calculation tool that is simple, easy-to-use, and accurate, particularly for different renewable energy technologies. This tool supports calculations across several European countries and is part of the Energy Communities Repository initiative (European Commission, 2019).
- **UNFCCC Greenhouse Gas Emissions Calculator**: Managed by the United Nations Framework Convention on Climate Change, this calculator aids in estimating GHG emissions. This is an excel based calculator. It supports initiatives such as Climate Neutral Now and is a part of the broader efforts by the UNFCCC to promote transparency and reporting on climate action (UNFCCC, 2021).
- **US EPA Simplified GHG Emissions Calculator**: In the United States, the Environmental Protection Agency, offers a Simplified GHG Emissions Calculator. This tool is aimed at small businesses and low emitter organizations, helping them to estimate and inventory their annual GHG emissions. It covers both direct and indirect emissions from all sources within an organization (United States Environmental Protection Agency, 2023).

To summarize, all 4 basic calculators mentioned above are not fully user friendly and are based on excel type spreadsheets basis. It is more suitable for personal GHG emissions calculations and make bigger awareness of companies which uses those tools.

International practices of GHG calculators and tools in AFOLU sector

International practices in GHG platforms and calculators for the AFOLU sector include tools developed to estimate GHG emissions and carbon sequestration.

- **EX-Ante Carbon-balance Tool (EX-ACT):** Developed by the UN Food and Agriculture Organization (FAO), the EX-ACT is a user-friendly tool designed for estimating GHG emissions and carbon sequestration in AFOLU projects. This tool is particularly useful for project developers and professionals working in agriculture, forest, livestock, watershed restoration, and grassland management, as well as those interested in GHG accounting in the AFOLU sector. The tool covers a global scale and is applicable to all forest types (natural and planted). It's an e-learning type tool, making it accessible for a wide range of users (FAO - SFM Tool Detail, 2019).
- **AFOLU Carbon Calculator**: The AFOLU Carbon Calculator, supported by the United States Agency for International Development (USAID) and Winrock International, employs IPCC-based accounting methods. It allows users to estimate the CO2 benefits and potential climate impacts of various land-based project activities like forest protection, forest management, afforestation/reforestation, agroforestry, cropland management, grazing land management, and forest degradation by fuelwood. This tool is particularly useful for investors to understand IPCC emissions related to potential carbon offsets (AFOLU Carbon Calculator | Impact Toolkit, 2014).
- **Agriculture GHG Calculators on AgLEDx Resource Platform**: This platform offers a range of GHG calculators designed for easy use with minimal data to quantify GHG emissions and removals in agriculture. These tools are based on IPCC guidelines and are suitable for non-specialists. They provide an accessible approach for estimating GHG impacts from agriculture and are recommended for raising awareness and planning action, despite a high level of uncertainty associated with their use (Agriculture GHG Calculators » AgLEDx Resource Platform, n.d.).

3. Best practices assessment in carbon monitoring and sequestration

3.1 National efforts of carbon sequestration in LULUCF sector

Lithuania has a National Energy and Climate Action Plan (NECP) for 2021-2030, which meets the requirements set out in the Energy Union Management Regulation. In NECP the policy measures for the implementation of the objectives and targets of the National Strategy for the Climate Change Management Policy 2021-2030 are included. The policy measures presented are divided into three groups:

- Existing policy measures (WEM) are already approved by legislation and have clear implementation mechanisms and secured funding. The impact of the WEM package and externalities on the achievement of national targets is described as an WEM scenario;
- Planned policy measures (WAM) presented in the green tables are proposed as complementary measures to the WEM package to achieve the 2030 targets, but are not currently approved by legislation or strategic planning documents and/or their implementation depends on the availability of different sources of funding. The impact of WAMs on the achievement of national targets has been assessed by modelling the WAM scenario;
- The alternative policy measures presented in a separate list for each sector were additionally included in the National Plan, taking into account the proposals made in the public consultation. They have not been taken into account in the calculations in part B, but these measures will be considered as an alternative to the elements of the WAM scenario in order to achieve the national targets prior to approval thereof in the legislation.

Planned and/or alternative policy measures will be adopted in 2020 and beyond, transposing them into sectoral development programmes or other strategic planning documents and/or other legislation. Planned and alternative policy measures, prior to their inclusion in sectoral development programmes or other strategic planning documents and/or other legislation, will be assessed in terms of their financial, economic, social, and environmental benefits, choosing the most efficient set of measures and the means of their implementation that will ensure the achievement of the objectives and targets of the 2021-2030 energy and climate change management policy. The results of the policies adopted and implemented will be regularly monitored and compared with forecasts. In the event of underperformance, consideration will be given to ways of replacing ineffective measures with more effective measures and/or increasing the scope of the measures chosen, the economic and legal signals to encourage the preferred conduct of market players and consumers will be reinforced and/or brought forward, and the public will be consulted on changes to the policy and measures. To this end, an inter-institutional working group will be set up to regularly analyse the results of the monitoring of the indicators of the National Plan, to discuss the effectiveness of the implementation of the measures under the approved policy and the need for additional policy measures, and to consult the public.

The sector of land use, land use change and forestry

The Lithuanian progress strategy 'Lithuania 2030' mentions that Lithuania is renowned for its rich nature and it must be important for Lithuanians to preserve and develop natural heritage and to use resources wisely. Initiatives for fundamental change in the area of the smart economy aim at ensuring the stability of ecosystems and protecting biodiversity through sustainable development of forestry. The National Strategy for Sustainable Development examines the possibilities of afforestation of more fertile soils in the LULUCF sector, identifies the need to use economic and administrative measures to ensure successful recultivation of used up quarries and peat bogs and maintenance of abandoned old farm buildings and provides for the possibility of creating conditions for landscape protection, management, use and planning by drawing up a national landscape management plan. Spontaneous

renaturalisation and a targeted increase of the Lithuanian forest area as well as other perennial vegetation areas, rational development of protected areas and the nature framework, as well as their integration into the international ecological networks will help to protect landscape and biodiversity, slow down processes of soil erosion and strengthen ecological stability of territories. According to the mission, implementation of the Lithuanian Programme for Forest Area Expansion will not only facilitate the use of unproductive farmland, but also supplement the missing elements of the nature frame, and, upon establishment of the necessary links, to facilitate the integration of the Lithuanian system of protected territories into the European ecological networks. The National Forest Sector Development Programme 2012–2020 aims to increase forest cover to 34.2% of the territory by 2020 through afforestation of uncultivated land and financial incentives for reforestation activities. During the period covered by the Lithuanian Rural Development Programme, i.e. 2007-2013, 17 200 ha were afforested and 8400 ha were afforested in 2014–2016. The draft National Programme for the Development of the Forestry Sector 2021–2030, which is due to be drawn up by the end of 2020, will aim to promote sustainable forest management and increase the absorption potential of the LULUCF sector. The objective of the Landholding Programme is to improve the structure of agricultural holdings and to reduce the areas of abandoned land. Measures have been put in place to achieve that objective: restoration of productive abandoned land to good agricultural condition, including land reclamation work (assessment criterion: 90 ha of restored farmland in 2020); preparation of low-productivity areas not suitable for agricultural activity for afforestation, including nature frame formation, and creation of an ecologically stable landscape.

Existing Policy Measures (2021-2030):

- **L1-E.** Restoration of peatlands (restoration of the hydrological regime on agricultural land). To identify the territories of former peat wetlands, where it is appropriate to restore wetlands, identifying the effectiveness of such wetlands in absorbing GHG. Promote the restoration of drained wetlands (peat wetlands), restoring the appropriate water level and supporting ecosystems in them through sustainable economic activities, paying special attention to wetlands, the development of which would contribute to the development of a circular economy, the preservation of natural habitats. Total GHG reduction effect: -812 kt CO_2 eq 2021-2030;
- **L2-E.** Preservation of grasslands and species habitats. The measure is intended to encourage farmers to preserve meadows and natural habitats. The measure provides for compensation for farmers who meet the stipulated requirements (TI05eko6 2.1 - For the management of natural grasslands of EC importance; KP070untž Protection of wild birds outside the "Natura 2000" territory; KP07ntž Support for "Natura 2000" agricultural land). Total GHG reduction effect: -184 kt CO_2 eq 2021-2030;
- **L3-E.** Conservation of wetlands. The measure is intended to encourage farmers to conserve wetlands. Provides compensation for farmers who meet the stipulated requirements (TI05eko6 2.2 - For management of wetlands of EC importance; TI05eko7 Extensive management of wetlands). Total GHG reduction effect: -159 kt CO_2 eq 2021-2030;
- **L4-E.** Promotion of cover crops. By implementing this measure, agricultural entities will be encouraged to grow cover crops, increasing the area of cover crops will not only improve the agrochemical composition and physical properties of arable land, but will also significantly contribute to the reduction of environmental pollution and negative changes in climate change (TI05eko1.2 Activities on arable land - Cover crops). Total GHG reduction effect: -3357 kt CO_2 eq 2021-2030;
- **L5-E.** Promotion of crop rotation. Under this measure rotation of at least 4 crop cultures will have a positive effect on maintaining soil fertility. Moving away from monoculture and crop rotation will increase the amount of organic carbon in the soil. By contributing to increasing soil carbon sequestration and reducing GHG emissions, the measure will have a direct impact on the achievement of climate change mitigation and adaptation goals. The measure provides for

compensation for farmers who meet the stipulated requirements (TI05eko1.1 Activities on arable land - Plant change). Total GHG reduction effect: -4424 kt CO_2 eq 2021-2030;

L6-E. Restoration of peatlands (translation into grasslands). Replacing arable peatlands with grasslands will have a positive effect on the reduction of GHG emissions from peats, the preservation of soil fertility, the reduction of erosion, the formation of which is greatly influenced by intensive agriculture, and the increase of the amount of organic matter. The measure aims to contribute to reducing the extent of plowing of peatlands (organic soils), promoting the restoration, preservation and regular maintenance of herbaceous plant cover of organic soils. (TI05eko4 Replacement of arable peatlands with meadows). Total GHG reduction effect: -967 kt CO_2 eq 2021-2030;

L7-E. Promotion of green cover. The measure aims to reduce soil erosion and GHG emissions, increase the amount of organic matter in the soil and biomass, by installing grass strips, and by installing and maintaining meadows in eroded land areas. Turning arable land into grassland contributes to stopping soil erosion and reducing GHG emissions. Total GHG reduction effect: -190 kt CO_2 eq 2021-2030;

L8-E. Preservation of landscape elements. The measure aims to preserve and restore the traditional mosaic landscape. In areas with high mosaicity, conditions are created for the living and reproduction of various plant and animal species and thus contribute to the preservation of biological diversity. The landscape elements will protect the soil from erosion, so the measure can have a direct positive impact on the implementation of the national goals of preserving soil fertility, increasing the amount of organic matter, reducing erosion, as well as, depending on the type of landscape element, reducing GHG emissions and increasing absorption. Total GHG reduction effect: -146 kt CO_2 eq 2021-2030;

L9-E. Afforestation. The measure aims to increase the forest coverage of the country by providing support to private land owners for forest planting, maintenance and protection (7 years after forest planting). Total GHG reduction effect: -143 kt CO_2 eq 2021-2030;

L10-E. Young forest thinnings. The measure aims to strengthen the resistance of forest ecosystems to negative environmental factors, form targeted stands, increase the productivity and absorption potential of stands. Total GHG reduction effect: -72 kt CO_2 eq 2021-2030;

L11-E. Development of agroforestry and agrohorticulture. To define the concept of agro-forestry and agro-horticulture economic activity, applicable in Lithuania, based on the best experience of other countries. Assess the possibilities of growing perennial plants (agro-forestry and agro-horticulture) on agricultural land (according to the specifics of land use) and the economic, social and environmental (including carbon accumulation) potential of the products grown or the raw material obtained, as well as the development of mixed perennial plant-pasture systems;

Total national effect of WEM measures -10,455 kt CO_2 eq.

Additional policy measures in the LULUCF sector

These measures were additionally included in NECP, in line with the proposals received during the public consultation. Their effect are taken into account in the last calculations and these measures will be considered as an additional to the elements of the WEM scenario in order to ensure at least the same effect on the achievement of the national targets prior to approval thereof in the legislation.

Additional policy measures:

L12-P. Preservation of grassland area. The measure stipulates an obligation for farmers who have perennial meadows on their farms to preserve them. If the farmer destroyed such a meadow in the past, he would be obliged to restore it. Total GHG reduction effect: -62 kt CO_2 eq 2021-2030;

L13-P. Promoting carbon sequestration farming (on agricultural land). The instrument seeks to promote the development of carbon-storage farming practices and, where necessary, the development of regulatory measures, thereby encouraging the long-term storage of organic carbon in soil, dead organic matter and biomass, ensuring additionality and sustainability, and respecting biodiversity and overall;

L14-P. Preservation of tree selfies. The measure is intended to support the preservation of self-grown trees (compensating part of the lost agricultural income and costs of inclusion in forest land accounting), with the aim of 2030. increase the area of newly planted forests. Total GHG reduction effect: -748 kt CO_2 eq 2021-2030;

L15-P. Improving the quality of forests. The measure is intended to support forest restoration with valuable tree species and redevelopment of rarefied and low-value stands in order to achieve more resilient and more CO_2-absorbing forests. Total GHG reduction effect: -126 kt CO_2 eq 2021-2030;

L16-P. Determination of GHG indicators. Determine national indicators of greenhouse gas emissions and indicators of changes in carbon stocks in order to refine the current accounting of greenhouse gas emissions/absorption and to provide the most appropriate measures for reducing greenhouse gas emissions and increasing absorption in the GHG sector.

L17-P. Promotion of carbon storage farming (in forests). The owner of a private forest, who has determined that it is necessary to carry out (intermediate) felling for the development of young trees or thinning or to apply other carbon accumulation farming measures in the forest under his control, initiates the appropriate actions necessary for support for the compensation of the costs incurred during felling or during the application of other carbon accumulation farming measures. The amount of compensation would depend on the type of deforestation or the application of a specific measure

L18-P. Forest planting. About 300 ha of new forests would be planted on state land every year in order to increase the country's forest areas. Total GHG reduction effect: -72 kt CO_2 eq 2021-2030

L19-P. Promotion of organic construction. The measure includes: 1) the implementation of pilot building renovation (modernization) projects using standardized modular structures made of organic materials and, based on them, the preparation of recommendations for the mass application of these solutions, which would allow an average reduction of primary energy consumption by at least 30 percent. (2023-2025); 2) support for the implementation of standardized modular constructions from organic materials in Lithuania, necessary for the implementation of the goals set out in the Long-Term Renovation Strategy. Total GHG reduction effect: -1052 kt CO_2 eq 2021-2030;

L20-P. Restoration of peatlands (restoration of the hydrological regime in forests). Currently, the status of Natura 2000 habitats 9080 and 91D0 is assessed as Unfavorable Unsuitable (U1). This condition was caused by climate change and the renovation of old drainage systems in these habitats. In order to avoid emissions from these wetland forests, it is planned to preserve or restore the hydrological regime. Total GHG reduction effect: -40 kt CO_2 eq 2021-2030

Total national effect of WAM measures -1,848 kt CO_2 eq.

3.2 Carbon certification

Carbon farming becomes more widespread every year. Some countries have already started their own carbon certification before the adoption of European carbon certification regulation. Currently the leaders in this regard are France, Germany, Finland, and Spain. These countries have established carbon certification framework on state or private levels, and it will be discussed later in this section. However, firstly it is required to discuss which methods for monitoring, reporting and verification they are using. Currently there are many international and national carbon certification methodologies that are being used. Most prominent international ones are Verra and Gold Standard. These methodologies consist of certifications for different activities with guidelines for each activity.

Verra

Verra is one of the most widely spread methodologies used for carbon certification throughout the world. This certification body was founded in 2007 and now it manages the world's leading voluntary

carbon markets program, the Verified Carbon Standard (VCS) Program (1). Only in 2022 it issued more than 1.04 billion carbon credits (2). These credits were approved by more than 70 VCS standards that are currently in use for Verra.

Every single one of VCS standards has a comprehensive carbon credit monitoring system that are described in methodology handbooks. These methodologies vary from "Improved Forest Management through Extension of Rotation Age" to "Energy Efficiency and Fuel Switch Measures in Thermal Applications"(3). However, in the GFarm project framework only those methodologies considering Agriculture, Forestry and Other Land Use (AFOLU) sector are being analyzed.

Monitoring. Currently there are 19 methodologies of carbon certification for the AFOLU sector in VCS standards. Out of these 19 methodologies 13 considers carbon certification in forests, while agricultural lands, grasslands and wetlands has 2 methodologies each. However currently there are only 5 VSC standards that are deemed eligible for financing. These standards are applied for selected carbon pools that best describe the carbon emissions reduction or absorption increase. Furthermore, carbon pools have their own separate methodologies, that are called "modules" for calculating carbon. These modules are applied for ex-ante and ex-post evaluations of projects when monitoring plans are made. They range from modules on how to estimate above- and below-ground biomass in live tree and non-tree pools (4) to estimating emission reductions from avoiding unplanned deforestation (5). Modules provide information on applicability conditions, which procedures of measurements must be done, data and parameters that have to be tracked in the project plan. Depending on when modules were updated, they use either IPCC devised or VCS approved methodologies for carbon pools.

As aforementioned modules have the applicability conditions. This part instructs on which land-use and its conditions and parameters module could be used. It may range from forests of all types and age classes (4), to delineate non-peat versus peat and to stratify the peat according to peat depth and soil emission characteristics in peatland rewetting (6). Furthermore, procedures of measurements are described in great detail. There are descriptions of frequency of measurements to estimation of carbon stocks in different carbon pools in different measurements designs (4). Finally, data and parameters are described, where basic information about them and justifications of use are provided.

Reporting. Following these modules project monitoring plans are made that describes what parts in it has to be included, for e.g.:

1. Monitoring of project implementation
2. Monitoring of actual carbon stock changes and greenhouse gas emissions
3. Monitoring of leakage carbon stock changes and greenhouse gas emissions
4. Ex post estimation of net carbon stock changes and greenhouse gas emissions

For each of these tasks, the monitoring plan must include the following information:

1. Technical description of the monitoring task
2. Data to be collected (the list of data and parameters to be collected must be given in project description
3. Overview of data collection procedures
4. Quality control and quality assurance procedure
5. Data archiving
6. Organization and responsibilities of the parties involved in all of the above (4).

These monitoring actions are important for defining the project baseline before start and adjusting it for every following carbon credit issue period. According to carbon certification methodology project proponents must detail the procedures for collecting and reporting all data on which the certification is based upon. These data must be collected on already set parameters at described intervals of time.

Verification. Validation and verification is one of the most important parts of any carbon credit project. Verra established that these processes are conducted by separate third party bodies (VVB) – qualified, independent third-party auditors. During verification, a VVB confirms that the outcomes set out in the project documentation have been achieved and quantified according to the requirements of the respective standard (7). There are rules for validation and verification that VVB's have to comply with

which are described in "VCS Standard" (8). The general concept is that "Verification is the periodic ex-post independent assessment by a validation/verification body of the project and its GHG statement of emission reductions and carbon dioxide removals that have occurred as a result of the project during the monitoring period." Furthermore, there is an extensive list of requirements that binds VVB to ensure the highest standards of carbon credit quality during the verification process. This ensures that only verification bodies with most experience and appropriate competencies can verify the carbon credits, which ensures its reliability.

Gold standard

Another popular carbon certification methodology is "Gold standard". Gold Standard was established in 2003 by WWF and other international NGOs to ensure projects that reduced carbon emissions featured the highest levels of environmental integrity and also contributed to sustainable development (8). Throughout the world there are more than 150 million credits issued, that are valued 46 billion dollars of shared value created. Similarly to Verra, Gold Standard issues methodologies that are applied for relevant projects. Currently there are 11 methodologies concerning the AFOLU sector.

Monitoring. Gold Standard has robust requirements for projects monitoring and tracking carbon changes per action taken in accordance with methodologies. These monitoring standards are in line with IPCC guidelines methodologies, as they are based on carbon pools described in aforementioned guidelines. Gold Standard methodologies outline the importance of base scenarios, from which carbon credits shall be counted. They further provide guidelines for measurements required to compile this baseline scenario. Furthermore, there are outlined parameters and data, which are required to collect during project (9). This methodology outlines the frequency of data sampling during the project's duration, while also describing the requirements for collected data storage. In essence this monitoring approach is very similar to Verra's, while also providing more flexibility on base values used in calculations.

Reporting. Gold Standard requires annual project reporting (10). With the failure to provide an annual report the project may face the de-certification. This is the required information to provide in the report:

1. A summary of the recent activities, events and actions related to the Project,
2. A clear statement on how stakeholders may provide inputs/grievances,
3. A list of all inputs/grievances that have been received since the last Annual Report together with their respective answers/actions,
4. Any incidents or events that may impact the Outcomes/Impacts delivered to date (in terms of loss) or the ongoing Performance of the Project,
5. Any legal contest or dispute that has arisen,
6. Any updates to the Key Project Information, Project Design Document, Monitoring & Reporting Plan and any other supporting documentation,
7. A brief descriptive summary of all monitoring information collected during the year,
8. Any update of the 'Project Participants & Secured Titles' (in case of changes)

Verification. Gold Standard uses the same form of verification scheme as in Verra's case, where it is done by third party organizations – Validation and verification bodies (VVB). VVB has to meet the requirements of the Gold Standard outlined. It has to be accredited by ISO standards, UNFCCC-CDM Accreditation or have ASI-FSC Certification Body status. During the verification procedure the VVB appoints audit team, audit planning, site visit, assessment of conformity to the Principles & Requirements, or earlier versions of Gold Standard and associated standard documents and submission of a Validation or Verification Report with opinion (positive or negative) to SustainCERT (11).

Der Wald-Klimastandard

Even though, that Verra and Gold Standard are the most widespread carbon certification methodologies, they still get a competition from the new certification schemes entering the framework. One of these new-commers is Germany based forest certification body "Der Wald-Klimastandard" or

"The Forest Climate Standard". First version of the Forest Climate Standard has been officially available since 16 October 2023. Currently this certification scheme is only operational in Germany (12).

Monitoring. Currently "Der Wald-Klimastandard" has only 2 certification schemes for Forest Reconstruction and Forest conversion. Both schemes use same methodology of monitoring. There is an extensive list of criteria, that carbon certification schemes use – geographical, legal and temporal for project description and planning of implementation. During planning the most important carbon pools are selected and they include, but are not limited to soil organic carbon, bushes, deadwood, above- and below-ground biomass. Furthermore, the baseline scenarios are modeled for the projects carbon credits output. Also, available data is based on remote sensing data, which helps to accommodate with the cost of monitoring. These steps help to make carbon certification projects transparent with clear view of additionality they create (13).

When the project starts first monitoring activities begin from the 5th year and after that every 3-5 years. This timeframe is argued, because in the first 5 years newly reconstructed areas does not have enough biomass from young trees to be picked by remote sensing. Further monitoring is carried out depending on the availability of remote sensing data.

Reporting and Verification. Each project under "Der Wald-Klimastandard" certification has to be approved by independent quality service provider. These certifiers have to have a valid accreditation to one of the following quality standards:

1. FSC or PEFC in the field of 'Forest Management'
2. ISO 14065 for ISO 14064.3
3. UNFCCC as DOE (link) or AIE (link) under the scope '14th Afforestation / Reforestation'

For further transparency requirements, the certifier has to be changed at least for every third certification project.

The subsequent certification reporting that happens after monitoring shall include the following information:

1. Certification Organization Details
2. Description of the people involved in a certification and their competencies
3. Description of the objectives and scope of the certification, as well as its level of security and materiality
4. Timeline of the certification process
5. General description of the project, the forest owner, and the project participants
6. Summary of the certification, including the number of certificates and list of certified areas
7. Individuals who have reviewed the certification report internally
8. Number of Inquiry/Corrective Action Request (IN/CAR) resolved during the certification process
9. Clarification Requests (CL) that are the basis of the test in addition to the current version of the standard
10. Details of possible Forward Action Request (FAR)s
11. List of on-site observation protocols, interviews conducted and information viewed (documents, photos, etc.)

In the certification report, the certifier confirms for "Der Wald-Klimastandard" that:

1. the start of the project is duly justified*
2. the ownership, rights, processes and quality are duly justified
3. the financial additionality of the project is duly justified*
4. compliance with social and environmental protection measures is justified by certification according to PEFC/FSC
5. the areas and input parameters for the reference and project scenario are duly justified
6. the projected number of certificates determined and their differentiation into removal/avoidance is considered plausible

7. the conformity of the project with a checklist of indicators created on the basis of the Der Wald-Klimastandard online platform

*- Only at the start of the project.

Label Bas Carbone

The Low-Carbon Label (Label Bas Carbone) was created by Decree No. 2018-1043 of 28 November 2018, amended in March 2022 by France government (14). The Low-Carbon Label only recognises emission reductions made on French territory. Emission reductions are assessed according to a methodologies approved by the Minister for the Environment. The prefect of the region is responsible for examining applications for the labeling of a project, for the verification of the project and for the recognition of emission reductions for the benefit of the financier. Finally, the decree recalls the principle of additionality (a principle recognized worldwide) according to which emission reductions can only be recognized if they are additional to a reference situation. Emission reductions are not transferable on a secondary market after recognition to the original funder of the project.

Monitoring. Currently there are 3 approved forestry carbon certification methodologies under "The Low-Carbon Label". They are Afforestation, Reconstruction of Degraded Forests and Coppice to Forests. In Afforestation and Reconstruction of Degraded Forests "The Low-Carbon Label" for biomass change in the projected area uses "Long-Term Average Carbon Stock for ARR Projects with Harvesting" model proposed by Verra (15). This model provides examples for calculating the long-term average carbon stock for a variety of afforestation and reconstruction (ARR) projects scenarios with harvesting. After assessing the quantity of biomass in the project it has to be converted to carbon. For this procedure national and default coefficients from IPCC guidelines are used (16, 17). Carbon changes in soils are estimated by using national values derived from Arrouays et al. (2002) (18). First monitoring is done after 5 years from project start. Then the actual additionality from the base scenario is assessed.

Reporting and Verification. After implementing the project (generally 5 years after the notification date), the project manager has an audit of his project carried out by an independent auditor, in accordance with the indications explained in the method, or failing that in the order of November 28, 2018. Then, the project manager sends a formal request for verification of emissions reductions to the authority. This is composed in particular of a monitoring report, a verification report carried out by the auditor, useful elements to justify the choice of the auditor (19).

3.3 Technologies used in MRV

Monitoring, reporting and verification system is the key element to ensure the origin of carbon captured by certified forestry practice. Only credits approved by the MRV system could be counted as transparent and additional. MRV systems vary from "hands on" approach, where everything is verified in the field to more technologically advanced remote sensing or modeling solutions. The list of advanced solutions currently is exhaustive, but should be examined in more detail.

1. **Remote sensing**. This technology has developed to a point, where it could be called omnipresent in the scientific field of forestry and is also used in an operational fashion (20). It uses different technological solutions for National Forest Inventories, Management-level Forest inventories, Plot-level measurements, or temporally continuous forest monitoring. It can include wall-to-wall maps, very high spatial resolution satellite data, ground-based laser scanning or Aerial images. This technology helps to provide monitoring data, to make ground-measurements less relevant.
2. **Drones**. It is another rapidly emerging remote sensing technology, which helps to solve some vulnerabilities that traditional remote sensing technologies may encounter (21). It solves the problem of costs, bad weather conditions, which may interfere with quality of data received from such methods or rather infrequent temporal scale. Drones, equipped with GPS and digital cameras, are suitable for real-time applications, in as much as they combine high spatial resolution and quick turnaround times with lower operational costs. This technology may help to achieve the same or better results than

traditional remote sensing for a fraction of a cost, which is especially beneficial for monitoring small-scale forest owner holdings.

3. **GIS.** Geographic Information System (GIS) became one of the cornerstones for forestry in the passing decades. Forest management benefited the most from this technology introduction, because it helps to manage resources more efficiently, make more detailed decisions on harvesting or fire management plans. Furthermore, it provides foresters with the ability to make detailed maps and employ GIS for strategic planning and modeling (22). This technology helps carbon certification in every MRV step, since it is able to provide detailed predictions how forest management may impact the accumulation of credits, while also providing the tool for robust reporting and verification.

4. **Carbon budget models.** Modeling a forest carbon budget is generally considered an essential prerequisite to providing projections on different possible management scenarios in order to optimize the role of the overall forest sector in mitigating climate change. They can provide a dynamic simulation model that can represent a wide range of forest management activities, land-use changes, and natural disturbances (23).

5. **Soil carbon models.** Soils contain the largest terrestrial pool of organic carbon and soil carbon models help to predict its change for the future. It may become one of the fundamental instruments when predicting the carbon changes in soil, however currently these models show a high level of uncertainty and they require robust calibration for local context (24).

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