NATIONAL DEVELOPMENT PLAN 2020

EUROPEAN UNION
European Regional Development Fund

INVESTING IN YOUR FUTURE

Climate change mitigation potential of trees in shelter belts of drainage ditches in cropland and grassland

Nr. 1.1.1.1/21/A/030

Implementation period3/01/2022 – 30/11/2023

Latvian State Forest Research Institute SILAVA

&

Ltd "Latvian Rural Consultation and Education Centre"

Deliverable 4.2.

REPORT

Report on implementation of sustainability criteria and inclusion of the shelter belts in voluntary carbon trading platforms[1]

Salaspils, 2023

1 V01 – after acceptance or improvements suggested by by ERDF experts will be published online with ISSN number, first published online 2023-11-29 on https://www.silava.lv/en/research/active-projects/climate-change-mitigation-potential-of-trees-in-shelter-belts-of-drainage-ditches-in-cropland-and-grassland

Contents

Introduction

At the global level, discussions on carbon-related farming and forestry in principle began already in the first period of the Kyoto Protocol. New Zealand started testing the idea and the first standardization organizations were born. In the following years, as the global community moved toward ever-larger climate change mitigation goals, additional initiatives, including farm-level incentives, became increasingly relevant. The private sector's interest in the possibilities of offsetting irreducible GHG emissions in various sectors also grew.

The goal of the Paris Agreement (2015) - to ensure the balance of all anthropogenic greenhouse gas (GHG) emissions and CO_2 capture by the second half of this century – creates additional climate policy challenges, and the package of EU Green Deal (2019) documents already clearly outlines the need, along with the climate change measures used so far to implement new reduction strategies, including in cooperation with the private sector. New initiatives in the land sector have been assessed as particularly important, because according to the European Commission's (EC) strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy statement to the European Parliament, the European Council, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank "A clean planet for all!" scenario of climate neutrality until 2050, currently formulated as the overarching goal of the EU Green Deal, special importance is foreseen for the land use, land use change and forestry sector. The capture of CO_2 created in the sector together with technological CO_2 solutions must cover the irreducible GHG emissions in other sectors. Taking into account the challenges contained in this goal, it is precisely in the field of land management that hitherto less used motivation tools for private landowners are being sought and the EC recognizes and emphasizes carbon-based farming as one of such additional mechanisms that can be used effectively.

The idea of carbon-based farming includes practices that improve the sequestration of CO_2 from the atmosphere by converting it into plant biomass and/or soil organic matter and specific financial incentives for agricultural and forest land owners to implement these practices in a result-oriented manner. Ways in which this process can be stimulated include the creation of a system of trading of certified carbon units in the field of land management, where this practice has not been widespread in EU countries so far.

The purpose of this study is to evaluate the current EC proposals for the implementation of the carbon-related farming initiative during the implementation period and the available information on the carbon unit certification and verification systems used in the European Union countries. The tasks set to achieve the goal of the research include preliminary proposals for the implementation of the carbon-based farming system in Latvia, prepared on the basis of currently available information, and the analysis of two (currently identifiable) cases of carbon-based farming activities.

Proposals of the European Commission for the implementation of the carbon-related farm initiative

The possibility of creating a carbon-based agricultural system in the EU was initially outlined in the Commission's statement to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "Sustainable bioeconomy for Europe. Strengthening economic, societal and environmental engagement" (COM (2018) 673 final) and in the accompanying European Commission working document (SWD (2018) 431 final). Anticipating the rapid expansion of the bioeconomy in Europe, specific measures of the strategic implementation program are planned to highlight the potential of the bioeconomy, including the implementation of pilot measures for increasing the synergy of EU local action supporting instruments and a clearer orientation towards the development of the bioeconomy. As one of the pilot measures, a pilot study on the possibilities of creating a carbon-based farming system is planned, with the aim of encouraging member states to create funds (voluntary principle) that would deal with the purchase of CO_2 credits from farmers and foresters who implement specific projects, as a result of which the accumulation of carbon in the soil and biomass will increase and GHG emissions will decrease. The idea of carbon management is planned as an approach that would ensure the creation of a results-based payment system for rewarding farmers and foresters (clearly defined public funding payment) for providing a public service (carbon sequestration and GHG emissions reduction). Thus, the provision of a public service (carbon sequestration or GHG reduction) would be made an economically viable agricultural or forestry activity.

The goals of creating a carbon-based farm system:

- more efficient use of natural and financial resources;
- reduction of GHG emissions in the life cycle of agricultural production and food supply chains;
- testing of innovative financial initiative systems with the aim of reducing GHG emissions.

The implementation of a carbon-based agricultural system would support the implementation of policies, regulations and programs such as the Common Agricultural Policy, Land Use, Land Use Change and Forestry (Land Use Change and Forestry) Regulation, the EU Bioeconomy Strategy, the EU Circular Economy Action Plan and, at the global level, the Paris Agreement and the Global Alliance for climate-smart farming. It is predicted that by 2024, as a result of the implementation of the carbon-related farming initiative, GHG emissions will decrease.

In the Annex to the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "A New Circular Economy Action Plan For a Cleaner and More Competitive Europe" (COM (2020) 98 final) "A New Circular Economy Action Plan for a Cleaner and More Competitive Europe" (COM (2020) 98 final) ranks among the main activities of the action plan the development of a regulatory framework (until 2023) for the certification of carbon sequestration units, based on the principles of complete and transparent accounting, ensuring monitoring of carbon sequestration units and verification of their compliance.

The Commission's communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "Strategy "From Field to Fork" for a Fair, Healthy and Environmentally Friendly Food System" (COM (2020) 381 final) talks about a new green business model – carbon sequestration provided by farmers and foresters. The strategy emphasizes that practices that ensure atmospheric carbon sequestration should be rewarded through either the Common Agricultural Policy (CAP) or private initiatives. A reliable carbon market should be created to ensure the operation of private initiatives, including comprehensive regulations for the certification of carbon sequestration units in the agricultural and forestry sectors. The existence of such a comprehensive certification system is a prerequisite for the initiation of carbon sequestration payments to farmers and foresters. Member States will be able to use these certification rules to design CAP payments based on the amount of carbon sequestered. Private companies could also be interested in purchasing carbon sequestration units or certificates, thus supporting the reduction of climate change and providing additional initiatives (to the actions included in the CAP). The new EU carbon sequestration initiative within the Climate Pact will support this new business model, which will provide farmers and foresters with additional income while helping other sectors (farming) to decarbonize food chains. As mentioned in the EU Circular Economy Action Plan (COM (2020) 98 final), The EC will develop a regulatory framework for the certification of carbon sequestration units based on complete and transparent carbon accounting with the aim of verifying the authenticity of carbon sequestration units. In the framework of the CAP, the measures of carbon-related farming, in the opinion of the EC, should be ranked among the new eco-schemes, as one of the sustainable farming practices, along with precision farming, agro-ecology, incl. for organic farming and agro-forestry.

Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "Increasing the scope of Europe's 2030 climate plans. Investing in a climate-neutral future for people' (COM (2020) 562 final) regarding the update of the 2030 Climate and Energy Policy Framework in the LULUCF sector emphasizes the need to motivate farmers and foresters to take actions that support carbon sequestration in soil and forest at an individual level. It was emphasized that currently everything basically depends on the activity of the member state, but it is necessary to develop the certification systems of carbon-related farming and carbon sequestration units by 2030. It was emphasized that within the framework of the EU Climate Pact, carbon management will be demonstrated and popularized as a new business model.

Proposal of the European Commission for the regulation of the European Parliament and of the Council supplementing Regulation (EU) 2018/841 with regard to the scope, simplification of compliance rules, determination of Member States' objectives for 2030 and progress towards the common achievement of the goal of climate neutrality by 2035 for land use, land use change and in the forestry and agricultural sectors, and Regulation (EU) 2018/1999 regarding the improvement of monitoring, reporting, progress assessment and review (2021/0201 (COD)) links the implementation of a carbon-based agricultural system to the accounting of wood products (Article 9 of the Regulation), emphasizing such the growing importance of new products such as construction materials, fibers and polymers. Article 9 of the LULUCF regulation is planned to be used as a platform for the certification of carbon sequestration units and carbon-related farming, using wood products as one example of an emerging carbon farming system. Clause 10 of the preamble of the LULUCF regulation proposal emphasizes the need to create new initiatives that would stimulate the increase of CO_2 sequestration and refers to new business models based on the idea of carbon-based farming. It was emphasized that such models and initiatives would stimulate climate change mitigation in bioeconomy sectors, including wood products. The implementation of the carbon management initiative through new business models would not only introduce agricultural and forestry practices that increase CO_2 sequestration, but would also contribute to balanced territorial development and the viability of the rural economy, while creating new jobs and stimulating various types of training opportunities. The EC emphasizes the setting of minimum carbon sequestration targets at the national level and, accordingly, the creation of innovative carbon sequestration initiatives (e.g. carbon-based farming) as a "key" tool to reduce GHG emissions in the EU. How the specific goals and initiatives will be implemented is left to the discretion of the various levels of institutions in the Member States.

EC working document, impact assessment report for the European Commission's proposal for a regulation of the European Parliament and of the Council supplementing Regulation (EU) 2018/841 with regard to the scope, simplification of the eligibility rules, the setting of Member States' targets for 2030 and progress towards the common goal of climate neutrality by 2035 land use, land use change and forestry and farming sectors, and Regulation (EU) 2018/1999 on improving monitoring, reporting, progress assessment and reporting (SWD(2021) 609 final), describes the establishment of carbon-based farming/market-based carbon trading as The EU's long-term progress towards the creation of a cost-effective policy framework with the aim of ensuring the climate neutrality of the land sector. The system should work at the land property level.

Conceptually, the system is described as corresponding to the approach used by the European Union (EU) Emissions Trading System (ETS) for the performance of industrial producers to achieve the ETS goals. In contrast to the ETS, emission units in the land sector carbon trading system are planned to be progressively linked to carbon sequestration certificates to ensure transparency on the move towards climate neutrality. It is emphasized that such a system would ensure equal conditions in the EU's internal agricultural market. The approach requires:

- the establishment of a comprehensive certification system;
- capacity of landowners and institutions to ensure monitoring of generated GHG emissions and capture.

Both conditions are expected to be addressed at the EU level:

- by 2023 by creating a carbon sequestration certification mechanism (according to the EU Circular Economy Plan);
- by the end of 2021 by publishing the EU Carbon Agriculture Initiative (as published in the EU strategy "From field to table").

In the period until the fulfilment of these conditions (establishment of the EU Carbon Sequestration Certification Mechanism and publication of the EU Carbon-Related Agriculture Initiative), the CAP will continue to support sustainable land management practices and technologies and access to consulting services and monitoring tools. Thus, while working on the development of parallel initiatives at the level of individual landowners, the main concentration of efforts is currently directed towards the development of more ambitious climate change mitigation strategies in the land sector at the national level.

Although the EC documents emphasize the connection of the CAP with the carbon-based farming initiative, there is still a discrepancy between the time of document development and implementation. The CAP strategic plan must be submitted to the EC by the end of 2021, but the EU Carbon Agriculture initiative will also be made public by the end of 2021, and the development of the certification system for carbon sequestration units is planned by the end of 2023. Since the practical policy planning document (CAP Strategic Plan) precedes the development of the regulation for the creation of the carbon-related agricultural system, it is not clear how the linking of these regulations/documents is planned, which is, however, mentioned several times in various documents (Figure 1).

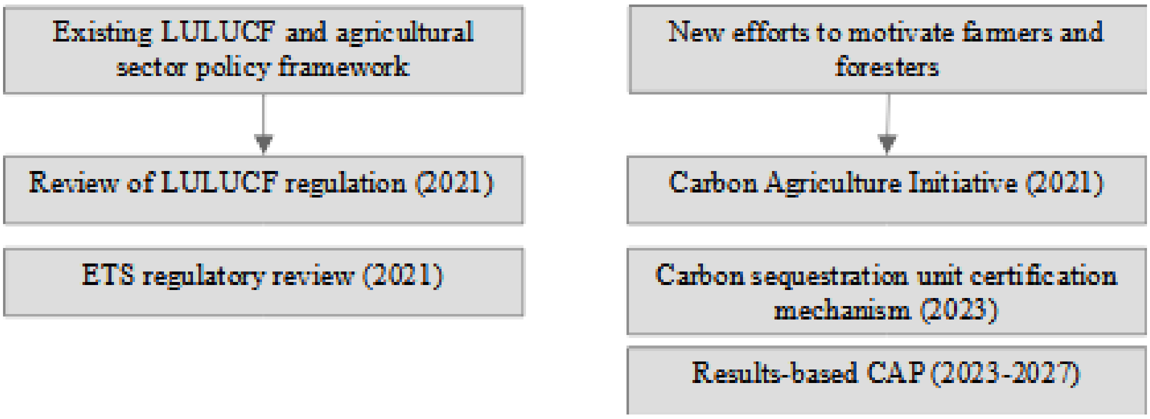

Figure 1. The framework of the EU political regulation for the climate neutrality of the land sector at the level of the state and individual farms[2].

Towards the integrated achievement of the climate change policy goals of the LULUCF and agricultural sectors in the period after 2030, the impact assessment report of the LULUCF regulation proposal (page 30) and the regulation proposal itself outline the need for member states to submit national plans, explaining the contribution towards the goal of neutrality of the land sector in 2035. year. Among other things, the plans should explain the importance of various nationally selected financial sources (CAP funds, EU regional funds, state support, private funds – for example, the creation of voluntary trading systems for carbon-related farming) in achieving this goal. Thus, the EC emphasizes low-carbon farming not only in the context of the CAP, but also highlights the involvement of the private sector.

The impact assessment report of the proposal for the LULUCF regulation currently concerns the theoretical possibility for farmers and foresters to sell carbon sequestration units on the voluntary market, and the accepted carbon unit price is 10 EUR. At the same time, the report emphasizes that at the time of its preparation, accurate estimates of the amount of expected economic benefit at the level of individual landowners are not available. At the EU level, it is estimated that the benefit could be around EUR 700 million (68.3 Mt CO_2 eq.), but the time period to which it applies is not mentioned.

The impact assessment report of the proposal for the LULUCF regulation includes the member state level recommendations prepared by the EC in 2020, which are recommended for use in the preparation of CAP Strategic Plans. The recommendations include 'key' areas on which Member States are advised to focus in order to ensure the achievement of the strategic objectives of the CAP, including climate change mitigation and adaptation. The recommendations summarize climate change mitigation strategies that are recommended as the most effective at the level of a specific member state. The creation of a carbon-based agricultural system has been recommended to a number of countries, but not to Latvia. From the Baltic States, the approach is recommended for Estonia (Table 1).

[2]Source: adapted from the impact assessment report of the LULUCF regulation proposal.

Table 1. EC recommendations for implementation practices of low-carbon farming systems in the context of CAP development[3].

Member State	Recommended Practices for Carbon Farming Systems
Belgium	improvement of lawn management and gentle tillage
Croatia	carbon sequestration practices in forest and grassland
Czech Republic	unspecified
Denmark	management of carbon-rich soils and peat soils
Estonia	protection of peat soils
In France	carbon storage in perennial grass
Greece	unspecified
Hungary	unspecified
Ireland	stopping peatland degradation and promoting restoration
Italy	practices that improve the use of resources
Luxembourg	carbon storage capacity of forest and perennial grassland
Malta	unspecified, general capacity improvement
The Netherlands	wetland restoration
Spain	unspecified

In general, the EC's recommendations for the implementation of the carbon-related agricultural system in the member states, using the CAP instruments, are basically focused on the management practices of long-term grassland, wetlands/peats and forests, which would promote carbon sequestration. Italy is recommended to consider the possibilities of working towards the efficiency of resource use, the Czech Republic, Greece, Hungary, Malta and Spain are generally advised to use the business approach of the carbon-based agricultural system, without specifying specific areas of activity.

Annex 10.7 of the impact assessment report of the LULUCF regulation proposal discusses the implementation of the carbon-related agricultural system in the EU. It was concluded that there is currently no policy instrument available that would enable targeted work towards increasing carbon sequestration and preserving existing carbon stocks. The EU carbon-based farming initiative is planned as a new green business model that would reward the implementation of climate-friendly practices through the CAP or other public or private initiatives, thus stimulating private landowners to implement these practices and at the same time earn additional income. It was emphasized that this initiative could also help to achieve the goals of the EU Forest Strategy, Biodiversity Strategy and Adaptation Strategy.

In connection with the implementation of the carbon-related farming initiative, the impact assessment report of the LULUCF regulation proposal distinguishes 3 recommended scenarios:

1. implement the system within the CAP Strategic Plan. The EC mentions the recommendations prepared by the member states for the most effective measures to reduce climate change, where a system of carbon-related farming is recommended for individual countries, and separately emphasizes the framework of the reinforced conditions system in relation to the protection of carbon stores, as well as eco-schemes and rural development interventions, as well as additional opportunities to increase the amount of carbon sequestration outside the framework of the reinforced system of conditions. It is mentioned that CAP measures can provide broad support and involve landowners also through such measures as consultations, knowledge transfer, non-productive investments. However, the recommendations are of a very general nature, no specific examples are mentioned or specific recommendations are given as to how exactly the mechanism of carbon-related farming should be included in the CAP;
2. Combining KL and private initiatives. In this case, the CAP support could be the basic financing for the creation and operation of the carbon farming system, while the landowners would benefit

[3] Source: LULUCF regulation proposal impact assessment report.

financially by selling the carbon sequestration units on the market. Due to the fact that it takes time to create carbon capture units and correct accounting, it is recommended to use different forms of CAP support aimed at supporting landowners in creating a carbon capture unit trading business – for example, additional payment or compensation for lost income. support for the development of the monitoring system;

3. State support for the operation of the carbon-related farming mechanism. A more detailed description of the options is not given.

It was emphasized that carbon-related farming business initiatives and carbon sequestration unit calculations should be based on a clear calculation methodology, a complete monitoring, reporting and verification (MRV) framework, reward and sanction mechanism, and management rules should be developed. The provisions of these conditions will be developed at the EU level within the framework of the Carbon Removal Certification (CRC), which will be prepared by the EC during 2022 and is planned to be adopted in 2023. The framework for the certification of carbon sequestration units is planned as a normative regulation/legislative proposal. The carbon sequestration unit certification mechanism will create a regulatory framework for the certification of carbon sequestration units based on complete and transparent carbon accounting,

It will be essential to create a reliable management system that will guarantee the additionality and permanence of carbon sequestration units related to the land sector. By the end of 2021, the EC will publish a communication document ("Restoring sustainable carbon cycles"), which will include an action plan for both initiatives: 1) carbon-related farming; 2) carbon sequestration certification mechanism.

Technical guidelines for the creation and implementation of a results-based carbon-based farming system in the EU

On April 27, 2021, the EU published the proposals of the results of a two-year study on the creation of a carbon-based agricultural system in the EU. The results of the EU-commissioned study carried out in 2018-2020 are summarized in the report "Technical guidelines manual – creation and implementation of a results-based carbon-based farming mechanism in the EU". The system of carbon-based farming is perceived as an opportunity to ensure carbon sequestration, contributing to the achievement of the EU's climate change reduction goals, while at the same time creating an opportunity for agricultural and forest land managers to earn additional income. The results of the study could serve as non-binding, orienting guidelines to encourage the private sector and state institutions to think about the possibilities of implementing a carbon-based farming system.

The guidance document provides an overview of the experience to date in the planning, design and management of carbon-based agricultural systems. Existing examples of carbon management mechanisms are analysed in five areas of activity:

1. Peat re-naturalization (restoration of the initial moisture regime): emphasized as a potentially effective measure in EU countries with significant GHG emissions from managed, reclaimed organic soil, incl. in Latvia. An EU-level example is the "MoorFutures" project;
2. Agroforestry: integrated systems of woody plants and field plants/farm animals recommended for cropland and grassland on the grounds that such systems act as carbon sinks. An EU-level example is the "UK Woodland Carbon Code" project;
3. preservation and increase of soil carbon stock in mineral soil: practices that increase soil carbon storage – improved crop rotation, agroforestry, prevention of conversion of grassland to cropland and conversion of cropland to grassland. The uncertainty and variability of available data and environmental conditions are emphasized. There are currently no good examples at EU level;
4. management of soil carbon stock in grassland: the positive contribution is based on increasing soil carbon accumulation in such measures as preservation of existing grasslands, conversion of unmanaged areas into grassland, conversion of arable land into grassland and avoided emissions without converting grassland into arable land. An EU-level example is the Burren Programme;
5. Farm carbon audit: carbon auditing on farms is understood as computerized systems that calculate the farm's GHG emissions and other indicators (for example, the nitrogen balance) with the aim of

achieving a farm's GHG emissions that are below the existing baseline. An EU-level example is the French "CARBON AGRI" project, Solagro, Cool Farm Tool.

Technical guidelines document, as the most prospective carbon-related for the implementation of the agricultural system, the EU recommends the restoration of peatlands (relatively small areas, but a high potential for reducing GHG emissions) and agroforestry (potentially large available area, many side benefits, it is possible to develop new approaches). Grassland management activities could cover a large area, but it is relatively difficult and expensive to monitor and ensure sustainability. Farm carbon audit systems could be promising, but associated with relatively high uncertainty and there could be concerns about supporting intensive farming systems on land that could be managed more efficiently. Systems for preserving and increasing soil carbon accumulation in mineral soil are also associated with high uncertainty,

The guidance document distinguishes 2 approaches to carbon farming:

1. activity-based approach (the landowner is rewarded for carrying out specific measures, but the result to be achieved by them is not defined);
2. results-based approach (the landowner is rewarded for taking specific measures and the goal of reducing GHG emissions or increasing carbon storage is defined), but the entire document is prepared and oriented towards the implementation of the second type (results-based) approach, emphasizing that the CAP The initiatives of the 2nd pillar so far are basically considered action-based. Also in policy documents, in which carbon-related farming is mentioned, that the EU should create a support system for reducing climate change, its orientation to a results-based approach is emphasized.

The definition of carbon-based farming in the sense of the guidance document includes the management of carbon sequestration systems and GHG emission flows at the farm level in a way that mitigates the impacts of climate change. Both the agricultural and LULUCF sectors are included, forming the scope of AFOLU (Agriculture, Forestry and Other Land Use),according to the definition of the Intergovernmental Panel on Climate Change (IPCC) of the United Nations.

When evaluating the possibilities of creating a carbon-based agricultural system for one of the climate change mitigation activities, the guidance document recommends to carry out an evaluation by identifying areas and measures that correspond to local conditions and farming systems and to evaluate the measures by answering the questions:

1. whether there is evidence of a significant reduction in GHG emissions/increase in CO_2 sequestration as a result of the implementation of the measure and whether there are no identifiable significant negative side effects;
2. whether indicators are available that would prove the reduction of GHG emissions/increase in CO_2 sequestration, or whether such indicators could be identified as a result of research. Indicators must be directly related to the expected climate change reduction effect, easily measurable, capable of responding to changes in the management system, but resistant to the effects of external factors independent of the farm. The indicator must be able to measure the reduction of climate change in CO_2 eq., according to the current IPCC guidelines. The indicator could also be applied to emission reduction CO_2 eq. For measurements per unit of production (it was emphasized that the EU wants to maintain food production volumes), as well as in absolute terms). Indicator values can be both calculated (modelled) and directly measured in nature;
3. whether landowners might be prepared to take on the risks associated with implementing the measure following a results-based scheme approach. The risk could be related to external factors that make the result difficult or unattainable, such as various climatic factors;
4. whether the MRV system could be cost-effective for the selected indicators;
5. whether an independent climate change mitigation assessment audit system is available;
6. whether this type of carbon farming activity has already proven itself in the EU context.

When choosing an activity to form a carbon-based farming system, it is recommended to choose the climate change reduction potential of the measure in CO_2 eq yr^{-1} as the main criterion. However, this can often prove to be the most difficult step as such quantified information is often not available. Additional aspects that are recommended to be taken into account in the selection of the measure and that may need to be demonstrated are:

- Durability (permanence) – whether the climate change reduction effect achieved as a result of the measure will be long-lasting;
- Additional benefit (additionality) – whether the measure provides an effect that would not otherwise be achieved;
- The risk of carbon leakage (carbon leakage) - whether the implementation of the measure will not result in an increase in emissions elsewhere. For example, if grassland is maintained in one area, is there a risk that grassland will be set aside in another to maintain production and income levels. There are times when this is actually not preventable. Then, being aware of this risk, a part of the generated carbon compensation units can be withheld;
- Uncertainty (uncertainty) – whether there is a lack of data accuracy, whether reliable calculations can be obtained, or whether the necessary data for evaluation are available.

As an additional condition in favour of choosing a measure for the creation of a carbon-based farming scheme, the existence of positive side effects should be taken into account. For example, but not only – reduction of nutrient leaching, improved soil functionality, diversified farm income, etc. It is emphasized that these side effects are often difficult to determine and include in the assessment.

For the creation of a carbon-based agricultural system, the guidance document recommends a sequence of steps for one of the activities:

1. identify the essential components – what could be the climate change mitigation indicator (what data are needed), whether the necessary expertise and skills for implementation are available, what the potential source of funding could be, whether suitably qualified carbon sequestration auditors are available. The audit system can be built on the principles of self-examination, when it is carried out by the landowner himself. It is cheaper than an external audit, the landowner feels personal involvement, but such a system creates a greater risk of error and personal interest;
2. whether the necessary resources are available for the creation and maintenance of the system, whether it is possible to mobilize them in a predictable period of time. It is desirable to be able to calculate the costs of system creation and maintenance in EUR Mt^{-1} CO_2 eq;
3. whether there is confidence that the MRV system will make it possible to estimate the reduction of climate change with sufficient accuracy;
4. identify potential stakeholders (experts, farmers, foresters, state institutions) and choose a management system model;
5. create a management structure, coordinate the management idea with stakeholders, gaining their support;
6. to obtain approval for the creation of the system from the relevant state administration institution. Develop a system project plan, identifying specific tasks, timelines, milestones, division of responsibilities, and required resources.

Analysing the possible sources of funding for the creation of a carbon-related agricultural system for one of the activities, several options have been identified, in accordance with the existing practice:

1. **public funding** – the main source of funding recommended for EU countries to consider. The CAP framework is especially highlighted, emphasizing that it is already used for similar types of funding (mentioned EIP groups and potentially also LEADER projects). In the 2023-2027 period, it is recommended to consider the 1st pillar intervention and compliance rules. General instructions are given to include carbon-related agricultural activities in both pillars in the development of the CAP Strategic Plan and to explain this approach to farmers, foresters, consulting services. It is recommended to form working groups for the implementation of the carbon-related farming approach. Recommendation within the framework of the CAP regarding carbon-related agricultural activities to focus on eco-schemes and annual increased payment for peat soil with increased water level,

agroforestry systems and woody plant inclusions in agricultural land. At the same time recognized

2. **Private financing, carbon market**. A carbon market can be:
   1. Based on compliance market – carbon credits are used to fulfil obligations and private institutions purchase carbon credits to cover their GHG emissions. In this case, the demand is formed by politically determined goals – the higher the values of the goals, the greater the demand in the market;
   2. Voluntary market. There are no publicly determined obligations, carbon offsets are traded. These markets have so far been the most successful for developing carbon farming projects. Initially, the system requires external funding, but later the system becomes financially self-sufficient. Voluntary markets enable landowners to directly benefit from climate change mitigation practices. There are good examples of increasing carbon sequestration in forests and peatlands in the international voluntary market;
   3. In addition to private financing, supply chain financing can also be distinguished – cases where a company wants to take actions to reduce the carbon footprint of its production. The activities can be carried out both by the company itself and by its suppliers, for whom the company finances a certain carbon-neutral farming system, thus reducing the company's carbon footprint. Such an approach is often chosen by large producers and traders, for example in the field of food.

The collaborative approach of public and private financing is mentioned as one of the recommended practices. Public funding can be used to create the system, while private funding can be used to ensure its further operation. When introducing a privately financed system of carbon-related farming, it should be expected that the payback period of the initial investment in creating the system is relatively long.

The simultaneous existence of a voluntary carbon market and national climate change reduction commitments can create the risk of double counting. In cases where two parties simultaneously apply for the same emission reduction for the fulfilment of their goals and in cases where the same emission reduction unit is registered, for example, both in the voluntary system and in the fulfilment of state obligations. This means the need for a strict carbon accounting system and traceability of origin. The risk of double counting also exists in cases where a reduction of emissions created in one country is sold in another country, since the reduction of emissions may appear in the fulfilment of the obligations of both the country of origin and the buyer. In the case of CAP funding, the risk of double funding may arise, if the land owner receives the regular CAP payment for the activity and at the same time an additional payment for the result of this activity within the framework of the carbon farming system. In this case, the system is ineffective and does not provide additionality.

Carbon unit prices in different schemes and as the market situation changes, they can differ significantly and be highly variable. Among other things, they affect the costs of creating the MRV system, which can vary significantly depending on the source of funding, the carbon market (requirements are always stricter in the voluntary market) and, accordingly, the requirements set by the MRV. The guidance document emphasizes that carbon unit prices are much more stable in the case of public financing schemes because they are agreed upon. KLP is evaluated as a relatively stable source of funding, however, it is recognized that it is a 7-year funding and the positions of the next period may differ.

Management systems sufficiently broad and timely involvement of various interests (land owners, state administration, non-governmental organizations, consultants, business and scientific representatives) is essential in the creation. The guideline document mentions that in experience (MoorFutures scheme) systems that have established a monitoring group (state administration, landowners, NGOs, business, scientists) and a support group (methodology, data acquisition, processing, etc.) have proven themselves well. A component of the management system is an independent carbon unit audit/certification system. EU experience shows that a system in which the audit is carried out by the institution that developed the monitoring system can work effectively enough, but separate national certification systems can be created. This issue is planned to be resolved at the EU level by 2023 by creating a single framework for certification of carbon sequestration.

In the framework of management, the question arises as to whether results-based carbon-based agricultural systems can contribute to the achievement of national climate change mitigation goals, especially in cases where the system is managed by a state institution. To ensure that GHG inventory issues are sufficiently integrated, it is recommended that the governance design also includes an institution responsible for GHG inventory, which can create a register of carbon offset units, issue these units and track their use, thus adequately accounting for GHG reductions at the national level. In the event of the establishment of any low-carbon farming system in the EU, governance must ensure coordination with the CAP and demonstrate the additional effect of the system in relation to CAP schemes and conditionalities.

The following questions should be answered within the framework of the creation of the administration:

1. which ministry or other administrative institution will be responsible for the system;
2. with which other EU and national policies should the creation of the system be coordinated in order to avoid contradictions;
3. whether the carbon-based farming system to be created has sufficient connection with the national GHG inventory, how to coordinate this connection;
4. how to report system activity data to simplify their integration into the GHG inventory.

An important aspect of the creation of a carbon farming system for a specific operation is the development of a monitoring, reporting and verification system (MRV). The MRV system is necessary to be able to evaluate and prove the climate change mitigation effect of activities, it is the main tool to be able to prove the environmental integrity of the system – that the climate change mitigation effect is real, provides additional benefits, measurable, long-lasting, prevents carbon transfer and double counting. The main components of the MRV system:

- monitoring: quantification of GHG emissions and CO_2 uptake, data collection, calculation methodology;
- reporting: the procedure by which the participants of the carbon-related farming system collect and report monitoring data to the relevant institutions;
- verification: ensuring the truthfulness and accuracy of monitoring data.

This is often the most time- and cost-intensive part of building a system. If it is designed very strictly, it can be very expensive, which in turn can significantly reduce the potential for the implementation and successful operation of the relevant carbon-based farming system.

Monitoring part is usually both the most time-consuming and also the most expensive. The biggest challenge is to keep costs reasonable while providing sufficient accuracy. Each system will have its own specific monitoring approach. At least a Tier 2 (IPCC) approach should be used for performance-based monitoring of carbon-based agricultural systems. Soil carbon modelling is likely to require a Tier 3 approach.

The MRV system can be based on measurements in nature or on modelling results and so-called proxy or indirect indicators. Indirect and modelling approaches can significantly reduce costs, but the necessary data and ready-to-use modelling approaches are not always available, and these types of estimates may have significantly higher uncertainty. The availability of good quality data can be a limiting factor for the implementation of outcome-based systems.

Choosing the direct measurement approach for monitoring requires field data collection and laboratory work to, for example, calculate the change in the carbon stock in the soil or forest, which can be further converted into GHG reduction or sequestration. Modelling involves the use of measurable indirect indicators to build a model that, using its built-in relationships, is able to reliably calculate the impact of climate change mitigation. Modelling is especially widely used in agricultural animal systems, often based on many dozens of proxy indicators. In the case of each carbon-related agricultural system, its own individual system should be created by choosing and combining monitoring approaches.

Three conditions are important in choosing a monitoring approach:

1. based on a scientific approach. The results must be calculated with high reliability and in a transparent manner – the method must be clearly documented and preferably published in the scientific literature;
2. practical applicability. The monitoring approach should be relatively easy to apply in the given circumstances. Complex systems can be difficult to apply, which in turn can hinder system implementation. The amount of data to be collected should be proportionate, maximum use of already collected data is desirable (CAP data, data already collected for other purposes and used by institutions);
3. side benefits and evaluation of other goals. It is desirable that the monitoring system gives the opportunity to simultaneously assess the goals and side benefits of other policies, such as changes in farm productivity, positive biodiversity effects,

The monitoring system can be designed to be as accurate as possible, but then it will be cost-intensive and it is essential that ensuring maximum monitoring accuracy does not jeopardize the implementation of the entire system, making it too time-consuming and financially unprofitable in relation to the reduction of climate change that can be obtained. The strictness of the monitoring rules can be varied depending on the potential risk level of the system participant – for larger land areas or systems, it may be necessary to perform field measurements, but, for example, for small areas – use only emission factors or indirect indicators. Maximum focus should be on the use of existing data and research results. For example, when choosing a carbon audit on a farm as a system for carbon-based farming, you can use already existing GHG emission/attraction calculators,

The design of the MRV system should take into account and design how the system will cooperate with the national GHG inventory system. All types of calculations must comply with the IPCC guidelines, the same or more precise emission factors calculated according to the guidelines, the same or higher precision activity data and assumptions, respecting the division of IPCC land categories, should be used at the level of project systems. The link with the GHG inventory of currently used EU carbon farming systems tends to be a weak point, which creates the risk that the climate change mitigation effect does not appear in the national GHG inventory. GHG inventors should be involved in the development of all carbon-based agricultural systems.

At the beginning of the creation of the system, it is important to determine the base values, in the initial period measurements in nature at farm/field level might be necessary. All calculations must be made in accordance with the current IPCC guidelines. MRV system developers should be familiar with the IPCC guidelines, use national GHG emission factors and, as far as possible, use the same activity data used in the national GHG inventory. During the development of MRV, it is necessary to decide whether to use directly measurable or indirect indicators to evaluate the achieved reduction of GHG emissions or CO_2 sequestration. The GHG emission factors used in MRV can be obtained within the framework of the specific system development project (expensive, but low uncertainty), data from other projects under appropriate conditions (recommended approach – cost-effective and good uncertainty), national GHG emission factors (uncertainty increases, the less likely it is to take into account the specifics of the specific location), the default IPCC GHG emission factors (there are opinions that the default factors cannot be used in carbon-related agricultural systems, as they cannot represent the areas of the system. In the case of conservative factors, environmental integrity is not compromised, but economic losses are formed). In case of selection of indirect indicators, additional necessary field level measurements can be performed by the land owner thus becoming more involved in the process. However, if landowners are involved in MRV processes (acquiring and collecting field data needed to determine climate change mitigation), they should not spend more than 1 week per year on this work. The EC technical guidelines document emphasizes that otherwise the motivation of land owners' involvement will be significantly reduced. For any indicators before their inclusion in the MRV system, must be field tested. In the testing process, it is desirable to involve landowners as potential participants of the system, as well as various interest groups, in order to increase the transparency of the system being created and ensure that the interest groups value it as reliable. Ideally, proxy indicators are validated with field measurement data. For example, measurements of the carbon accumulation potential of different grassland management systems in the pilot territories, using them to recalculate the practice implementation area indicator into the carbon sequestration indicator, which will be further used by the MRV system. Before developing the system itself, pilot tests are highly recommended. It is important to identify and evaluate the positive side effects of the activity in the MRV system. For example, agroforestry systems usually have significant biodiversity-enhancing side effects. In the testing process, it is desirable to involve landowners as potential participants of the system, as well as various interest groups, in order to increase the transparency of the system being created and ensure that the interest groups value it as reliable. Ideally, proxy indicators are validated with field measurement data. For example, measurements of the carbon accumulation potential of different grassland management systems in the pilot territories, using them to recalculate the practice implementation area indicator into the carbon sequestration indicator, which will be further used by the MRV system. Before developing the system itself, pilot tests are highly recommended. It is important to identify and evaluate the positive side effects of the activity in the MRV system. For example, agroforestry systems usually have significant biodiversity-enhancing side effects. In the testing process, it is desirable to involve landowners as potential participants of the system, as well as various interest groups, in order to increase the transparency of the system being created and ensure that the interest groups value it as reliable. Ideally, proxy indicators are validated with field measurement data. For example, measurements of the carbon accumulation potential of different grassland management systems in the pilot territories, using them to recalculate the practice implementation area indicator into the carbon sequestration indicator, which will be further used by the MRV system. Before developing the system itself, pilot tests are highly recommended. It is important to identify and evaluate the positive side effects of the activity in the MRV system. For example, agroforestry systems usually have significant biodiversity-enhancing side effects. in order to increase the transparency of the system being created and to ensure that interest groups evaluate it as reliable. Ideally, proxy indicators are validated with field measurement data. For example, measurements of the carbon accumulation potential of different grassland management systems in the pilot territories, using them to recalculate the practice implementation area indicator into the carbon sequestration indicator, which will be further used by the MRV system. Before developing the system itself, pilot tests are highly recommended. It is important to identify and evaluate the positive side effects of the activity in the MRV system. For example, agroforestry systems usually have significant biodiversity-enhancing side effects. in order to increase the transparency of the system being created and to ensure that interest groups evaluate it as reliable. Ideally, proxy indicators are validated with field measurement data. For example, measurements of the carbon accumulation potential of different grassland management systems in the pilot territories, using them to recalculate the practice implementation area indicator into the carbon sequestration indicator, which will be further used by the MRV system. Before developing the system itself, pilot tests are highly recommended. It is important to identify and evaluate the positive side effects of the activity in the MRV system. For example, agroforestry systems usually have significant biodiversity-enhancing side effects. measurements of the carbon accumulation potential of different grassland management systems in the pilot territories, using them to recalculate the practice implementation area indicator into the carbon sequestration indicator, which will be further used by the MRV system. Before developing the system itself, pilot tests are highly recommended. It is important to identify and evaluate the positive side effects of the activity in the MRV system. For example, agroforestry systems usually have significant biodiversity-enhancing side effects. measurements of the carbon accumulation potential of different grassland management systems in the pilot territories, using them to recalculate the practice implementation area indicator into the carbon sequestration indicator, which will be further used by the MRV system. Before developing the system itself, pilot tests are highly recommended. It is important to identify and evaluate the positive side effects of the activity in the MRV system. For example, agroforestry systems usually have significant biodiversity-enhancing side effects.

The technical guidelines document highlights the elements to be included in the practical creation of the design of a carbon-based agricultural system:

- **defining objectives and eligibility rules**. Clearly defining the goal of a results-based carbon farming system can be complicated. It is necessary to understand whether the system will be oriented towards the reduction of GHG emissions, carbon sequestration or a combination of both processes. There are systems where the goal is clear (e.g. reduction of GHG emissions in farm animal systems), but there can be complex situations. Actions aimed at reducing GHG emissions have a lower risk of non-permanence, while increasing carbon storage is a slow process and involves a higher risk of non-permanence. In the development of eligibility rules (who can apply for participation in the system, which areas are eligible, etc.) significantly avoid overlapping with other support schemes and develop criteria that ensure sustainability, additional benefits, do not contribute to the risk of carbon transfer, reduces uncertainty and eliminates negative side effects. These criteria are different for each system;

- **choice of outcome indicator**. Climate change reduction indicators must be selected according to the approach of the IPCC guidelines and all calculations should be made according to the current IPCC guidelines. Indicators can be aimed both at GHG reduction and at increasing the carbon stock in the forest or soil. GHG emission reduction indicators usually have smaller uncertainties and are more robust compared to, for example, carbon sequestration in soil (lack of data, difficult to calculate, relatively higher uncertainty). The indicator can be - a reduction in GHG emissions in absolute terms, a reduction in the intensity of GHG emissions (productivity data are also required), for example per unit of productivity, or a combination. If intensity indicators are used, it must be possible to recalculate the reduction in absolute terms, because all carbon-based farming systems must be able to contribute in the context of the EU Climate Law. Indirect or proxy indicators can be used, although this always implies greater uncertainty. For example, in the case of grassland – increased indicators of biological diversity, improved water circulation, registered economic activities that have a certain potential for increasing carbon accumulation, etc. The use of direct indicators (for example, soil carbon measurements) can be costly and technically difficult to implement. More often, different types of indirect indicators are used, information about which can be obtained from other types of databases, however, in this case, field-level measurements are still needed, which can be performed by the beneficiary himself. although this always means more uncertainty. For example, in the case of grassland – increased indicators of biological diversity, improved water circulation, registered economic activities that have a certain potential for increasing carbon accumulation, etc. The use of direct indicators (for example, soil carbon measurements) can be costly and technically difficult to implement. More often, different types of indirect indicators are used, information about which can be obtained from other types of databases, however, in this case, field-level measurements are still needed, which can be performed by the beneficiary himself. although this always means more uncertainty. For example, in the case of grassland - increased indicators of biological diversity, improved water circulation, registered economic activities that have a certain potential for increasing carbon accumulation, etc. The use of direct indicators (for example, soil carbon measurements) can be costly and technically difficult to implement. More often, different types of indirect indicators are used, information about which can be obtained from other types of databases, however, in this case, field-level measurements are still needed, which can be performed by the beneficiary himself. soil carbon measurements) can be costly and technically difficult to implement. More often, different types of indirect indicators are used, information about which can be obtained from other types of databases, however, in this case, field-level measurements are still needed, which can be performed by the beneficiary himself. soil carbon measurements) can be costly and technically difficult to implement. More often, different types of indirect indicators are used, information about which can be obtained from other types of databases, however, in this case, field-level measurements are still needed, which can be performed by the beneficiary himself;
- **reward system design**. In most existing carbon farming systems, income is generated by selling the climate change mitigation effect (tons of CO_2 eq). Prices may be determined by the market or negotiated in advance. The prices are very different, the guideline document informs that in 2019, globally, the prices of LULUCF sector units in the voluntary market varied from 0.5 ESD to more than 50 USD per metric t CO_2 eq, the average price – 4.3 USD per metric t CO_2 eq. Prices were higher in the compliance market – 6-13 USD per metric t CO_2 eq. The performance of obligations in the market is affected by political decisions and the limits of permitted compensation units. Trading can have several schemes: 1) a single platform for projects of one carbon-binding agricultural system, which ensures the trading of carbon units generated by different projects. (MoorFutures example) 2) decentralized system – each project has its own register, whose integrity monitoring is delegated (Peatland Code example); 3) a centralized register for the accounting and trading of carbon units generated by various types of carbon-binding agricultural system projects (example of The Dutch Green Deal). A non-market, regulatory approach using the reverse auction principle can be used to determine compensation – a public institution can organize the purchase of carbon units, for example, for the purposes of fulfilling national obligations, by determining the required number of units and the

price and purchasing the lowest price offer at the auction. In this case, only projects with verified, approved systems and evidence for environmental integrity could participate. Using compensation determination, based on the evaluation of the incurred costs, the CAP approach approved by the World Trade Organization (WTO) is recommended - to compensate the costs and the lost benefits. The CAP is recognized as an obvious source of non-market funding, but the 7-year cycle could be problematic when results are measured in the long term. A flexible approach could be used for the transfer to the next period and also regarding the calculation of the annual payment – initially determine the amount of the payment based on the project plan, but if the MRV system shows that the climate change reduction effect is less than expected, reduce the next payments (or increase , if the opposite situation is found). a source of non-market funding, but the 7-year cycle could be problematic in the event that results are measured in the long term. A flexible approach could be used for the transfer to the next period and also regarding the calculation of the annual payment - initially determine the amount of the payment based on the project plan, but if the MRV system shows that the climate change reduction effect is less than expected, reduce the next payments (or increase , if the opposite situation is found). a source of non-market funding, but a 7-year cycle could be problematic in the event that results are measured in the long term. A flexible approach could be used for the transfer to the next period and also regarding the calculation of the annual payment - initially determine the amount of the payment based on the project plan, but if the MRV system shows that the climate change reduction effect is less than expected, reduce the next payments (or increase , if the opposite situation is found).

<u>The choice of reward time is also important</u>– ex-post after the climate change mitigation effect is achieved or ex-ante already before the climate change mitigation effect is achieved. Both choices have limitations and combined approaches can also be chosen:

1. most of the carbon-related agricultural systems are initially partially or completely financed from non-market or public financing for their creation;
2. choose ex-ante payment by buying ex-ante carbon units – reduction units that have not yet actually been created in nature. In this case, a price reduction of 10-15% is used on average and ex-ante units cannot be used in obligation-based markets, which are usually characterized by higher remuneration compared to voluntary markets;
3. up to 50% "advance payment" can be collected from buyers of reduction units by agreement, thereby obtaining funds for the operation of the system;
4. choosing a hybrid approach – an annual action-based payment to action implementers that covers the costs of implementing the action and an additional ex-post result-based payment based on the achieved climate change reduction results. An annual fixed ex-ante performance fee may also be paid, which is reviewed at the end of the period, adjusting accordingly for the difference between what was paid and what was actually achieved.

Most carbon-based farming systems could require support from CAP funding to offset the costs of farmers or foresters from the time of operational implementation costs to the time when the carbon units are generated, verified and realised.

1. **non-compliance management**. Inconsistency is basically related to the loss of permanence – it can be intentional (deliberate reversal of the implemented action) or accidental (fire disturbance, drought period that destroys the effect of the action). To manage accidental loss of durability, the accepted practice is to freeze a certain amount of reduction units (5-60% depending on the degree of risk determined) as a safety cushion. The safety cushion approach can also be used for the management of intentional loss of sustainability, but in this case methods such as: 1) initially selected eligibility criteria are chosen – evaluating which potential system participants might be less exposed to the risk of a reverse operational effect; 2) long-term contracts – agreements on maintaining the sustainability of activities; 3) special reward for guaranteeing durability; 4) educational and consulting work, to achieve an increase in the level of responsibility; 6) change of land ownership – not always possible, but could work in cases where the owner is ready to sell land that no longer brings productive income (flooded area) to a manager who is only interested in environmental factors; 7) prohibition of land use change – possible in certain cases.

2. **evaluation of the developed carbon farming system**. Evaluation is an essential part of implementing new systems. The evaluation requires the acquisition of additional information, which should be foreseen when creating the system. The evaluation gives a conclusion about the achieved climate change reduction effect, the reliability of the system, identifies problems and offers their solutions. The evaluation should touch on the success of the system implementation, climate change reduction effect, environmental and social side benefits and negative impact assessment, economic impact assessment, efficiency (adequacy of implementation, MRV costs) and fairness (distribution of costs and benefits among system participants). The evaluation is carried out by collecting data (scientific and economic data), interviewing both those farmers and foresters who participated in the system and those who did not, consultations with interest groups. Consultation and discussion with system participants and interest groups is equally important with scientific and economic data. The assessment is carried out on average once every 3 years, but in the case of CAP funding – at the discretion of the institution managing the CAP funding. The carbon farming system being evaluated needs to take into account the results and recommendations of the evaluation, which can be complex for the system actors, for whom the rules can be changed during the game. One of the solutions to this problem could be to apply the evaluation recommendations only to participants who join the system after the evaluation. but in the case of CAP funding – at the discretion of the institution managing the CAP funding. The carbon farming system being evaluated needs to take into account the results and recommendations of the evaluation, which can be complex for the system actors, for whom the rules can be changed during the game. One of the solutions to this problem could be to apply the evaluation recommendations only to participants who join the system after the evaluation. but in the case of CAP funding - at the discretion of the institution managing the CAP funding. The carbon farming system being evaluated needs to take into account the results and recommendations of the evaluation, which can be complex for the system actors, for whom the rules can be changed during the game. One of the solutions to this problem could be to apply the evaluation recommendations only to participants who join the system after the evaluation.

The technical guidance document identifies more difficult problem areas in relation to implementation of the carbon trading system:

- only the reduction of emissions is rewarded, not the existing carbon stock;
- there are often problems to ensure the necessary aspect of "additionality" in areas where the relevant type of management would be implemented even without the carbon-related farming initiative;
- the cost of generating carbon units within carbon-based farming systems could be higher than current carbon market prices;
- at the national level, it might be administratively easier to continue the usual support systems rather than to introduce carbon-based agricultural systems.

International commercial carbon certification platforms

Several independent certification standards are currently operating in the world. They were originally created to serve the mechanisms of the Kyoto Protocol. The voluntary carbon market is dependent on and linked to the compliance-based market. When enforcement-based market expansion (political decisions) is anticipated, voluntary market activity increases as operators prepare for the new situation. Once the new commitment market has stabilized, demand in the voluntary market will decrease.

Currently, the most important international carbon standards are Gold Standard and Verified Carbon Standard (Verra). International carbon certification standards are used to ensure the reliability and environmental integrity of carbon units entering the voluntary market and to avoid double-counting risks.

Golden Standard certification standard

Golden Standard is a non-profit organization that has been operating on the market since 2003, its founder is the World Nature Fund and a network of international non-governmental organizations. Similar to the Verra standard, its creation aims to provide high-quality certification for carbon units used in the voluntary carbon market. The standard sets high requirements for the development of MRV systems. A new methodology can be used only after it has been approved by the technical committee of scientific experts, evaluated by an internal audit and publicly communicated. Since the level of uncertainty of the results is difficult to quantify, the standard states that the input data (emission factors, activity data, etc.) must have an uncertainty level of less than 20% in a 90% confidence interval and this uncertainty must be published or otherwise reliably verified, for example within the IPCC.

Within the framework of this system, the compliance of projects is verified by independent third-party auditors, for the first time within 2 years of the implementation of the projects and again at 5-year intervals. According to the information provided in the EC technical guidelines document, the average cost and time consumption of certification of one carbon-related farming project to Gold Standard is as follows in Table 2.

Table 2. Average cost and time required to certify a low-carbon farming project to Gold Standard. Source: Report "Technical Guidance Manual – Development and Implementation of a Results-Based Carbon Agriculture Mechanism in the EU"

Unit	Costs, EUR	Comments
Validation of methodology (new method)	50000	Time spent – 5 months
Validation of the methodology (existing methodology previously approved elsewhere)	7500	Time spent – 2 months
Certification (camera inspection)	5000	-
Certification (audit)	30000-40000	-
Verification	30000-40000	The verification is carried out within 2 years after the start of the project and thereafter every 5 years
Verification report	1500	
Register opening	1000	-
Registration costs for 1 credit unit	0.30	-

For carbon-related farming projects in the AFOLU sector, the Gold standard has specially developed standardization rules that are updated annually. Areas of carbon-binding farming covered are afforestation, reforestation and agricultural (primarily agroforestry and grassland system management activities) projects.

Verra certification standard (Verified Carbon Standard)

The Verra standard has been operating on the market since 2007. Its purpose is to ensure high quality standards for the trading of carbon sequestration units in the voluntary carbon market. The seat of the Standard Board is in the USA (Washington), but the field of activity is global. The standard operates in several areas and one of them is the Verified Carbon Unit Standardization (VCS) program, within the framework of which it is possible for carbon-related farming projects to certify their systems and the resulting GHG reductions and capture increases for global trade in the voluntary carbon market. The VCS program has been operating since 2006, includes many areas, including the certification of carbon units generated by forest, wetland, agricultural land management activities.

After the certification of a carbon-based farming project in the Verra system, the resulting climate change reduction can be traded on the international market. The reduction is expressed in verified carbon units (VCUs). In order for a carbon-related farming project to be certified in the Verra system, it must fulfil the rules and requirements of the system: 1) a detailed carbon accounting methodology must be developed, in accordance with the Verra requirements; 2) the developed methodology must be subjected to an external third-party audit and Verra's internal camera and field inspections; 3) the project must be registered in the Verra register, which maintains information on registered certified projects, created and deleted carbon sequestration units.

The Verra AFOLU standard includes improved forest management practices, wetland protection and restoration, and conservation of grassland and shrubland systems. Verra is open to proposals for new ideas for certification areas – ideas can be submitted to Verra's quality assessment and control group. As the main risks in the field of AFOLU, Verra emphasizes the risk of natural disturbances (fires, diseases, pests) and the risk of carbon transfer. To mitigate these risks, Verra develops special assessment and mitigation tools. In order to reduce the risk of unintended sustainability, projects must develop a risk assessment (internal, external and natural risks), the assessment is verified by Verra's auditors, and the number of carbon units determined accordingly is credited to the risk fund, withholding it from being put on the market. For all projects, a certain number of carbon units must be credited to the so-called security bank – if the carbon units are lost for any reason (fire, pests, etc.), the units credited to the security bank may be cancelled. On the other hand, in cases where risks do not occur for a project, carbon units can be released for this project for use in the voluntary market. Regarding the risk of carbon leakage, Verra requires the definition, reporting and accounting of any potentially diverted units, as well as the development of mitigation strategies. Certified carbon units for carbon-related farming projects are awarded by Verra for the reduction of GHG emissions or increase in CO_2 sequestration calculated according to the certified methodology.

In the Verra system, it is currently possible to certify projects of the following fields of activity: 1) afforestation, reforestation and revegetation; 2) agricultural land management; 3) improved forest management; 4) reduction of emissions from deforestation and forest degradation (REDD); 5) prevention of transformation of grassland and shrubland; 6) protection and restoration of wetlands.

Verra projects are also subject to social and environmental impact assessment requirements. Project applicants must identify potentially negative environmental and socio-economic impacts and propose mitigation measures. Cost estimate of Verra Verified Carbon Standard is shown in Table 3.

Table 3. Cost estimate of Verra Verified Carbon Standard[4]

<table>
<tr><th>Fee</th><th colspan="2">Rate</th></tr>
<tr><td>Account opening fee</td><td colspan="2">USD 500 for each account opened with the Verra Registry, payable in full at account approval[5]</td></tr>
<tr><td>Account maintenance fee</td><td colspan="2">USD 500 per year for each account, payable in full at account approval and subsequently in January of each year</td></tr>
<tr><td>Pipeline listing request fee</td><td colspan="2">USD 1,000 for each pipeline listing request, payable at the time of the request</td></tr>
<tr><td>Project registration request review fee</td><td colspan="2">USD 2,500 for each project registration request, payable at the time of the request[6]</td></tr>
<tr><td>VCU issuance levy, including conversion of GHG credits from approved GHG programs</td><td colspan="2">USD 0.20 per VCU, payable at the time of the issuance request</td></tr>
<tr><td>Methodology review fees</td><td colspan="2">For new methodologies and major methodology revisions:
• USD 2,000 review fee due upon initial submission of the concept note (Step 2 of the Methodology Review and Development Process); plus
• USD 13,000 review fee due upon initial submission of the draft methodology (Step 3 of the Methodology Review and Development Process).
For new modules and tools or major revisions:
• USD 1,500 review fee due upon initial submission of the concept note (Step 2 of the Methodology Review and Development Process); plus
• USD 6,000 review fee due upon initial submission of the draft module or tool (Step 3 of the Methodology Review and Development Process).
For minor methodology, module, or tool revisions:
• USD 6,000 review fee due upon initial submission of the draft revision (Step 3 of the Methodology Review and Development Process).</td></tr>
<tr><td rowspan="3">Methodology compensation rebate</td><td colspan="2">For cumulative VCU issuances from the applicable methodology from 1 January 2023 to 31 December 2025[7] (see Section 3 for payment terms):</td></tr>
<tr><td># of VCUs issued</td><td>USD / VCU</td></tr>
<tr><td>1-1,000,000</td><td>USD 0.02</td></tr>
</table>

[4]Source: https://verra.org/wp-content/uploads/2023/03/Program-Fee-Schedule-v4.3-FINAL.pdf

[5]Note that a single account on the Verra Registry may be used to manage multiple projects, and to manage projects that are participating in more than one Verra program (e.g., VCS and CCB). It is not necessary to open separate accounts for each Verra program.

[6]Fees are not refundable if a project is rejected or a project request is denied. The fee is payable for each request, including a new request made in follow up to a previously denied request.

[7]For example, where the total volume of VCUs issued by projects using the applicable methodology totals 5.2 million VCUs, with one project issuing 4.7 million VCUs within the calendar year and a different project issuing 500,000 VCUs within the calendar year, the total methodology compensation rebate would be: [($ 0.02 x 1 m) + ($ 0.018 x 1 m) + ($ 0.016 x 2 m) + ($ 0.012 x 1.2 m)] = $ 84,400.

Fee	Rate	
	1,000,001-2,000,000	USD 0.018
	2,000,001-4,000,000	USD 0.016
	4,000,001-6,000,000	USD 0.012
	6,000,001-8,000,000	USD 0.008
	8,000,001-10,000,000	USD 0.004
	10,000,000-60,000,000	USD 0.002
Validation/verification body annual fee	**# of programs**	**USD / year**
	1 program	USD 5,000
	2 programs	USD 7,250
	3 or more programs	USD 9,000
	Payable in full at approval and subsequently in January each year. Additional programs approved throughout the year will be billed and payable upon approval[8].	
Gap analysis fee	Determined on a case-by-case basis	

Proposals for the implementation of the European Union's carbon management initiative

At the time of the preparation of the report, no information is available on the EU's policies and action plan for the implementation of carbon-based farming, as well as on a single carbon sequestration certification standard, which, among other things, will determine uniform MRV and management principles, compensation principles and an approach to solving issues of non-compliance (sanctions mechanism) in the form of a regulatory framework. As the currently available information on the EU's unified regulation is very limited, the opportunities to prepare proposals for the implementation of the carbon-related agricultural system in Latvia are also limited. Any approach chosen by an individual Member State must be consistent with the EU's common framework. Therefore, a detailed evaluation of options and preparation of proposals will be possible, as information on EU regulations becomes available, action plans and regulations for the certification of carbon capture units. The conclusions prepared within the framework of this study can be perceived as a rough approximation, according to the limited amount of information currently available.

Management

The management of carbon-related farm systems is the most important element for the successful implementation of the system, as it ensures the overall reliability of the compliance of the obtained carbon units, the adequate inclusion of the obtained results in the record of the fulfilment of state obligations, the dissemination of information by stimulating the involvement of relevant interested parties, the existence of sufficient consultation and support. Taking into account the fact that there are currently no official EC communication documents available on the basic principles of the carbon-related farming initiative and the planned carbon certification system, based on the experience of other countries, one can only roughly outline the main stopping points of management:

- an organization (governmental or non-governmental) that coordinates the creation and operation of the system;
- consulting support that attracts landowners and companies and develops a management strategy for the specific farm;
- audit and monitoring support (independent auditors or MRV system developer) - monitoring and verification of the implementation of climate change reduction activities;
- scientific support by providing consultations on the use of appropriate monitoring protocols, updating according to the latest data and making climate change mitigation estimates;
- financial support (public or private) providing funding for system implementation and development;

[8]If a validation/verification body that is already approved becomes approved for an additional program, only the incremental annual fee is due at the time of approval.

- monitoring support (involvement of state administration institutions, including those responsible for GHG inventory, farmers and environmental non-governmental organizations) to ensure monitoring and reliability of the system.

As one of the areas of activity, the Latvian Climate Law, which is currently under development, provides for the development of basic principles for the promotion and accounting of voluntary systems for CO_2 sequestration (Article 3, Subsection 11, Article 38) and gives the delegation for the development of the Cabinet of Ministers regulations, which would determine the procedure, requirements, content, deadlines , monitoring conditions and enforcement supervision, in which voluntary systems for reducing greenhouse gas emissions and sequestering CO_2 are created. The creation of such a regulation, being created in accordance with the EU's common guidelines, would provide a stable basis for the further development of the management system of carbon-related farming schemes. In accordance with this framework, the management system of any carbon farming scheme should be further developed.

The communication of the EC so far recommends to seriously evaluate the possibilities of establishing the implementation of carbon-related agricultural systems in connection with the CAP. Given the disconnection between the timeline for the release of the communication documents of the Carbon Agriculture Initiative and the time frame for the development of the CAP Strategic Plans, this recommendation is currently very unclear in the practical implementation process. Clearer communication of the common principles of the EU is needed. One of the possibilities within CAP funding could be support for the development and training of monitoring, reporting and verification systems of the most promising carbon-related farming measures in Latvia, in order to prepare the methodological basis for the implementation of specific schemes. monitoring,

Within the framework of the management system, it is important to exclude the risk of double accounting (in the case when the climate change reduction effect declared by a private institution is sold to another institution to compensate for its emissions, but at the same time it is also recorded as a reduction in the national GHG balance and in the case when two private institutions declare a GHG reduction using same carbon units). To prevent this risk, it is necessary to create an independent register managed by a public institution - common to all carbon-based farming systems implemented in the country and able to ensure that country-level reports to the EU and the United Nations General Convention on Climate Change (UNFCCC) reflect the transfer of carbon units generated by carbon-based farming between sectors. If such a register is not created by an institution, which is responsible for the national GHG inventory system, it should be developed in close cooperation with the mentioned public institution. Considering the complexity of the system and the growing ambitions of the climate change goals, the most recommended approach would be for the state institution responsible for the GHG inventory to undertake the creation of a unified national register.

The experience of the EU so far shows that, on average, it takes at least 2 years from the development of a carbon-related agricultural system to its readiness for implementation, if the data of already conducted studies are available for the developers. It is essential to ensure sufficient involvement of interested parties in the process of developing the scheme, thus ensuring support during its implementation stage.

Eligible areas/activities

In Latvia, the assessment of the areas or activities potentially attributable to carbon-related farming was made using the EC technical guidelines approach. The five proposed areas were comparatively evaluated according to the situation in Latvia and the available data, and an additional area was added – forestry, which is essential in Latvia's situation. The results of the initial approximate assessment are summarized in Table 4.

Table 4. Assessment of areas or activities potentially attributable to carbon-related farming in Latvia

Action	Peat re-naturalization (restoration of the original moisture regime)	Agroforestry	Conservation and increase of soil carbon stock in mineral soil	Management of soil carbon stock in grassland	Agricultural carbon audit	Carbon sequestration in forest management
Climate change mitigation potential	Conflicting data - there is research-based evidence for both a GHG reduction and an increase effect. Unclear interpretation in Latvian conditions.	Research-based evidence for reduction of GHG emissions from soil, increase in CO2 sequestration in soil and living biomass. Inclusion of an afforestation scenario that has strong evidence of climate change mitigation potential should be evaluated.	Data from the literature show the potential to reduce climate change.	Research results indicate a reduction in GHG emissions from the soil, an increase in carbon accumulation in living biomass.	Research data shows the complex climate change mitigation potential.	Information based on research results is available on the increase in CO2 sequestration and, accordingly, the potential of actions to reduce climate change. Different types of CO2 sequestration enhancement operations are possible.
Potential for developing a cost-effective MRV system	There is a lack of research data from Latvia, it is necessary to rely mainly on indirect indicators.	Data from studies conducted in Latvia and neighbouring countries are available and additional data from currently ongoing studies are expected (LIFE OrgBalt)	It is relatively difficult to monitor the operation, but long-term LV measurement data on carbon input into the soil with crop residues are available.	Local research data from ongoing research (LIFE OrgBalt) is expected in the near future.	There is potential for the development and adaptation of existing GHG emission calculators for operational MRV system development.	Data from studies conducted in Latvia and neighbouring countries are available and additional data from currently ongoing studies are expected (LIFE OrgBalt)
Potential side benefits	Returning the ecosystem to its pre-anthropogenic impact state.	Evidence for a significant improvement in biodiversity.	Improving soil fertility and agricultural system productivity.	A reduction in nitrogen runoff, an improvement in biodiversity could be identified.	Potential improvement of environmental data, increasing popularity of climate and environmentally friendly practices.	Ecosystem services – air and water. Biological diversity.
Potential risks	Low public acceptance, negative socio-economic impact on large areas, including outside the area of implementation of the activity.	There is a certain drop in the productivity of agricultural production.	Currently not identified.	There is a certain drop in the productivity of agricultural production.	Currently not identified.	Currently not identified.

The initial compliance assessment shows that in Latvia's situation, taking into account the existing practices and available data, four of the five areas proposed by the EC could potentially be effective, and in Latvia's conditions, an important area for which carbon-related farming measures could be considered is forest management in order to stimulate forest owners to introduce such management measures that would provide a demonstrable increase in CO_2 sequestration and help the country move towards achieving climate neutrality goals. The implementation of the peat soil restoration measure in Latvian conditions lacks the justification of the climate change reduction potential obtained from the research results, and although the EC guidelines emphasize the climate change reduction potential of this area,

The following were selected as the carbon-related agricultural activities for which a case study was carried out in Latvian conditions within the framework of this study:

1. afforestation of organic soil with birch, which does not directly correspond to any of the areas identified by the EC, but, according to the studies so far, has a significant potential to reduce climate change in Latvia;
2. transformation of arable land into grassland with organic soil, which corresponds to the area identified by the EC "Management of soil carbon accumulation in grasslands", specifying it in relation to the type of soil.

In the further study of the possibilities of introducing carbon-related farming, agroforestry, promotion of CO_2 sequestration in the forest, preservation and increase of soil carbon accumulation in mineral soil, carbon audit of farms and other types of activities in the management of soil carbon accumulation in grasslands should also be evaluated.

Procedures for monitoring, reporting and checking of accounting for carbon units

As the EU Technical Guidelines document acknowledges, currently only a few carbon-related agricultural activities (restoration of the moisture regime in peatlands and agroforestry) have good examples of MRV systems and even then the existing systems have certain limitations, as they are not directly applicable in a new region. Taking into account the current situation and the fact that the creation of an MRV system for the implementation of activities in the context of carbon-related farming requires significant time and financial resources, when working on the creation of a carbon-related agricultural activity system, it is necessary to plan sufficient resources and expert capacity in order to develop the potential performance indicator into a cost-effective MRV system. Setting up an MRV system can be very financially intensive, depending on how much research needs it involves.

Judging by the currently available information, a unified EU-level approach to the development of MRV systems is planned to be included in the regulation of the certification of carbon sequestration units. Since very little information is currently available about the content of this regulation, the work on starting the development of MRV systems for specific carbon-related agricultural activities can currently be based on the approach offered by the international certification system and work on obtaining research-based data. The creation of any MRV system requires research data on the actual reduction of GHG emissions/increase in CO_2 sequestration of the selected activity, emission factors and other supporting data for reliable impact monitoring. One of the approaches could be to collect a data set of previous and ongoing research results and findings, which can be further used for the development of MRV systems.

By following the information on the EC's work on the development of the regulation for the certification of carbon sequestration units during 2022, national research work can be accordingly coordinated and the development possibilities of the national approach can be planned according to the conditions of the EU regulation.

Identifying the impact of activities in the national GHG inventory

Linking carbon farming systems to the national GHG inventory is mandatory. This is emphasized by the EC carbon-related farming technical guidelines document and is necessary to minimize the risks of double counting. The involvement of GHG inventory providers in the development of the system is recommended from the moment of the idea. If the system is created without the involvement of the GHG inventory providers and the institution responsible for the GHG inventory, it is likely that a situation will be created when, during the implementation and implementation of the system, we will have to face various problems of non-compliance and there will be difficulties in proving the compliance and realization of the generated carbon units.

GHG inventors should be involved in the development of the MRV system from the beginning of the system's development and throughout its implementation, ensuring its consistency and compliance with the current IPCC guidelines, as well as identifying the necessary indicator indicators, so that it is possible to adequately include the reduction of climate change caused by carbon-related agricultural systems in the national GHG in inventory.

Climate change mitigation effect of shelter belts

The length of amelioration ditches in agricultural lands in Latvia is 43000 km. Assuming that 10-20 m wide shelter belts is established around each ditch with no restrictions on the installation of the shelter belts, potential of this type area of tree plantations can reach 63000 ha. Taking into account possible limitations identified in studies conducted in Latvia (Bārdulis et al., 2022; Lazdiņš et al., 2021; Melniks et al., 2022), in the operational impact calculations, it is assumed that 44000 ha of shelter belts can be planted.

Tree plantations can be used for biomass of woody plants for cultivation, to meet the growing demand for raw materials in the bioeconomy in an efficient and environmentally friendly way. Tree plantations have already proven their ability to reduce nutrients in run-off (they retain 30-99% of nitrates and 20-100% of phosphorus from run-off waters (Christen & Dalgaard, 2013). Research conducted in Denmark shows that the yield of wood biomass in water-ways in shrub plantations equal to 9 tons ha^{-1} yr^{-1} and in tree plantations – 6 tons ha^{-1} yr^{-1} (respectively, 150 MJ ha^{-1} yr^{-1} and 100 MJ ha^{-1} yr^{-1}). The study in Sweden from demonstrated a potentially significant contribution to climate change mitigation in shelter belts planted with willows – 11.9 t CO_2eq. ha^{-1} yr^{-1} compared to 14.8 t CO_2 eq. ha^{-1} yr^{-1} in the willow plantations fertilized with sewage sludge (Styles et al., 2016).

Estimating GHG emission reductions in tree plantations, a simplified calculation is used, which assumes a cycle of 20 years (Figure 2). The calculation includes uptake in living biomass, not taking into account potential uptake in wood products and the substitution effect.

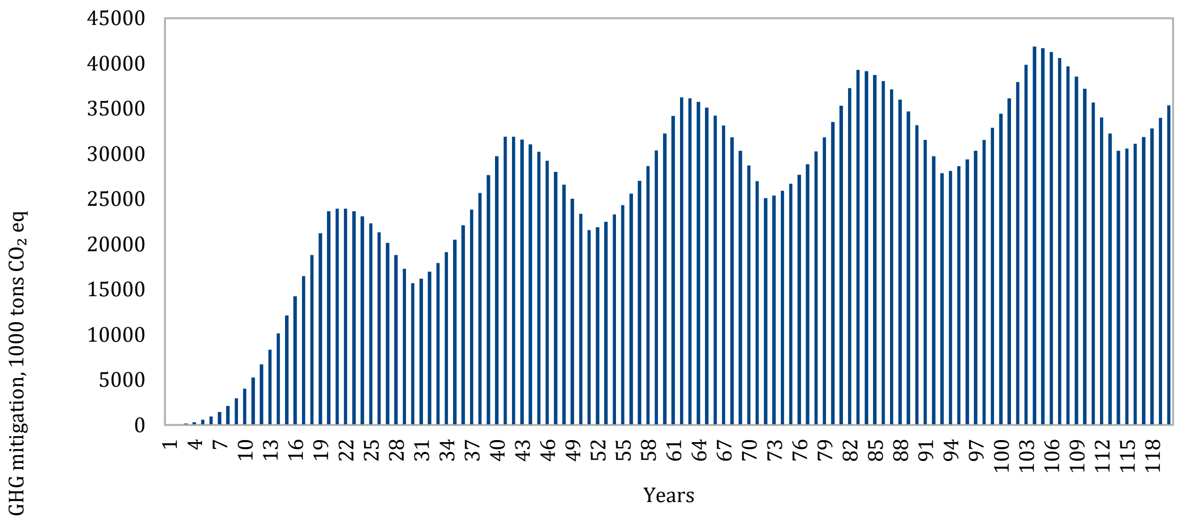

Figure 2. Cumulative potential reduction of GHG emissions in shelter belts in Latvia.

The total cost of the measure, according to the procurement carried out within the earlier commercial and research projects involving establishment of the shelter belts, during the first 3 years after the establishment of the plantation reaches 2602 € ha^{-1}. The cost of reducing GHG emissions with a 10% discount rate at the end of the first cycle in the 21st year is € 0.7 ton^{-1} CO_2 (Figure 3). Income from the sale of wood is taken into account in the cost calculation. Costs reach a minimum in 41st year, i.e. at the end of the second rotation cycle.

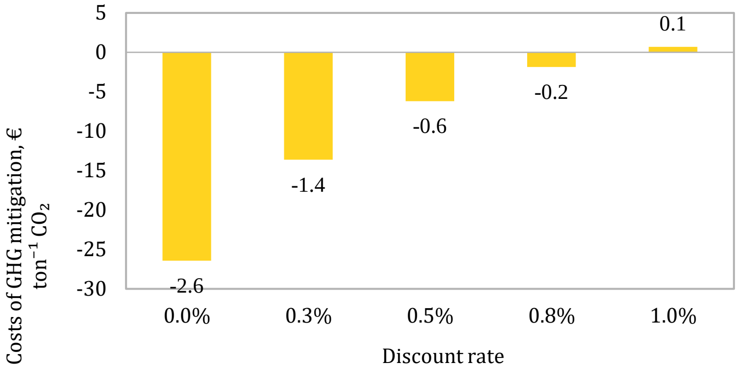

Figure 3. Cost of the mitigation effect under different discount rates

Summarized description of the measure according to criteria listed in the EC proposal for the voluntary emission trading system is provided in Table 5.

Table 5. Description of the measure

Parameter	Description
Objectives of the event	Economic objective: improve growing conditions in agricultural lands affected by tree belts, reduce natural losses caused by disturbances, diversifying production on farms and obtaining additional income by selling timber and wood biofuel. Climate objective: to increase carbon accumulation in ground cover plant biomass.
Areas that ARE suitable for the implementation of the measure	Suitable for the implementation of the measure on agricultural land (LIZ) bordering drainage ditches and where the field area is large enough for the establishment of tree plantations. The strips of trees should be installed in the path of the prevailing winds, taking into account that a strip of 20 m high trees improves the growing conditions in an approximately 60 m wide strip, accordingly, it is not useful to install strips of trees closer than 60 m from each other.
Territories that are NOT suitable for the implementation of the measure	Territories with restriction of economic activity areas where the planting of strips of woody plants is not allowed, forest edges, where the effect of the strip of woody plants is ensured by a forest wall (in such places, a strip of woody plants or shrubs contributes to the achievement of environmental protection goals by binding nutrients. Installation of tree strips is not recommended in places where they may threaten overhead power lines or where there is underground infrastructure in the area, including drainage channels. In places where the strip of woody plants crosses the drainage channel, a ditch (extension) can be dug or drainage pipes can be used, which cannot be overgrown with tree roots.

Parameter	Description
Event implementation technology	Before the implementation of the event develops a project for the placement of woody plant strips, plans additional shrubs (lower trees) strips on the windward side, as well as along ditches where periodic maintenance is required, plans openings for entering the fields and prepares the soil for planting woody plants. The soil is prepared in the same way as for cereals. In the previous year, it is preferable to keep the area fallow to get rid of weeds. After tilling the soil, trees are planted. Suitable tree species for tree strips are birch, aspen, poplar, black alder and other fast-growing tree species. Poplars are planted by machine using long (1.5-2 m) cuttings, other tree species are planted by hand (bare-rooted seedlings and frame seedlings) or mechanically (small-sized frame seedlings). Commercial varieties of willows are used in the bush strips, which grow back from the stump, so it does not go to the field and ditch and the area is then easily recultivated. It is also desirable to plant species in the tree belt, which regenerates mainly with stem shoots (poplar, birch). After planting, early maintenance must be carried out for at least 3 years, and if willows are also used in the strip planting, the willow crop must also be harvested once every 5 years. The duration of the cycle of woody plants depends on the tree species, it is the shortest for poplar hybrids (20-25 years). At the end of the cycle, logging is carried out and timber and wood biofuel are prepared. The cut area regenerates as a shoot, which is thinned out during early maintenance. In order to limit the spread of diseases, the strips of woody plants should be restored after the second or third rotation by pulling out the stumps, preparing the soil and planting new and more resistant planting material. The duration of the cycle of woody plants depends on the tree species, it is the shortest for poplar hybrids (20-25 years). At the end of the cycle, logging is carried out and timber and wood biofuel are prepared. The cut area regenerates as a shoot, which is thinned out during early maintenance. In order to limit the spread of diseases, the strips of woody plants should be restored after the second or third rotation by pulling out the stumps, preparing the soil and planting new and more resistant planting material. The duration of the cycle of woody plants depends on the tree species, it is the shortest for poplar hybrids (20-25 years). At the end of the cycle, logging is carried out and timber and wood biofuel are prepared. The cut area regenerates as a shoot, which is thinned out during early maintenance. In order to limit the spread of diseases, the strips of woody plants should be restored after the second or third rotation by pulling out the stumps, preparing the soil and planting new and more resistant planting material.
Restrictions on the implementation of the measure	Implementation of the measure can be limited by nature protection restrictions and requirements of maintenance of agricultural landscapes, as well as by technical limitations for the establishment or management of the shelter belts. The establishment of tree strips does not involve a change in land use.
The negative effects of the measure on the climate	The measure does not have a negative impact on climate change, but in the first years after tree planting, as soil structure improves, carbon loss from the soil may increase, which is offset by carbon input to the soil through litter in subsequent years.
Duration of the impact of the measure and actions to maintain the impact	The measure has long-term effect, which is determined by initial land use, used tree and bush species, duration of rotation and use of wood.
Effect of the measure on CO_2attraction	Net reduction potential of greenhouse gases due to planting of fast-growing poplar hybrids in 20 year-long rotation cycle ensures about 800 tons of CO_2 ha^{-1}(40 tons of CO_2 ha^{-1} yr^{-1}).Overall in 30 years this measure can provide 35 million tons of CO_2 eq. if 44000 ha of shelter belts are established.
Impact of the event on sustainability aspects	Shelter belts have important functions of preserving natural diversity, mitigating economic risks and mitigating the negative impact on the environment. They serve as a living environment and movement corridors for many animal species, provide a food base for pollinators, improve the moisture regime and reduce air temperature in adjacent areas, reduce wind erosion and retain nutrients, which are leaching to drainage ditches. Shelter belts can also become an important source of woody biofuel and timLV
The cost of implementing the measure	Establishment of shelter belts of woody plants costs in the first five years at current prices around 2500 € ha^{-1}. Costs during the rotation cycle (20 year) at current prices is approximately 9500 € ha^{-1}, including logging, but revenues – 20800 € ha^{-1}. Main cost items are soil preparation, purchase and planting of seedlings, early care and logging.
Income from the implementation of the event	Net income in one rotation cycle after selling of timber and biofuel timber and wood biofuel, at current prices is approximately 11300 € ha^{-1}.
CO_2 removal costs	Cost of CO_2 removals after 20 years long rotation cycle are -19 € ton of CO_2, i.e. the revenues exceeds the cost of the measure. However, farmers usually will need funds for initial investments, particularly, because there is no support for this measure in CAP.

Sustainability criteria for produced biofuel

The sustainability criteria were evaluated in connection with the draft regulations of the Cabinet of Ministers "Amendments to the regulations of the Cabinet of Ministers of November 2, 2022 No. 686 "Regulations on criteria for sustainability and greenhouse gas emissions savings, criteria for electricity produced from biomass fuel and procedures for justifying, certifying and monitoring compliance with the mentioned criteria" (hereinafter referred to as Regulations No. 686).

Calculations were made according to regulation No. 686 for the emissions of forest biomass raw material extraction and cultivation referred to in point 3 of Appendix 2 for the entire territory of Latvia (the e_{ec} parameter mentioned in point 3.1 of Appendix 2 of Regulation No. 686 – raw material extraction and cultivation emissions, and the e_{td} parameter – transportation and sales emissions) and forest annual emissions of biomass, which occur as a result of changes in land use and changes in carbon accumulation (the e_l parameter mentioned in paragraph 3.1 of Appendix 2 of Regulation No. 686 – annual emissions that occur as a result of changes in land use and changes in carbon accumulation), ensuring the necessary calculations of GHG emissions savings for members of the European Union emission allowance trading system. The calculation is based on regulation No. 686 and directive no. 2022/996 for the requirements of Annex 7.

Estimation of sustainability parameter e_{ec} and e_{td}

The calculation of e_{ec} (emissions from extraction or cultivation of raw materials) includes the following technological cycles of forest biofuel preparation – preparation of stump wood (felling related to the restoration of shelter belts), firewood in the main felling. GHG emissions are calculated for the technological cycle, including logging and transportation and chipping.

Emissions are calculated according to fuel consumption and taking into account the proportion of bio-additives in the fuel. In addition, GHG emissions related to the use of lubricants, oils and heat carriers in cooling systems have been assessed. The study prepared calculations that describe the total GHG emissions for forest biofuel production in 2022. The calculation uses scientific literature and publicly available information, forest resources monitoring data on logging and a survey of logging companies on the productivity and fuel consumption of logging equipment and road transport and information provided by equipment dealers on the consumption of oils, lubricants and air conditioning agents. The calculation of the total emissions caused by the preparation of biofuel is made from the average emission of the technological cycles of forest biofuel preparation listed above that are typical for Latvia. Emissions are not specific to 2022, as there is no information available on logging machinery and its productivity when working outside our forests, but the data presented for national forests are inconsistent and give different results when evaluating emissions as a function of productivity and average fuel consumption figures. Also, there is no information available on the production of wood chips from logging residues outside the state forests, so the ratio between logging and the preparation of logging residues, as it is in JSC "Latvia's state forests", is used to characterize it, while Forest Resources Monitoring data on logging outside forest lands in the previous five years. working outside state forests, but the data presented for state forests are inconsistent and give different results when evaluating emissions as a function of productivity and average fuel consumption figures. Also, there is no information available on the production of wood chips from logging residues outside the state forests, so the ratio between logging and the preparation of logging residues, as it is in JSC "Latvijas valsts meži", is used to characterize it, while Forest Resources Monitoring data on logging outside forest lands in the previous five years. working outside national forests, but the data presented for national forests are inconsistent and give different results when evaluating emissions as a function of productivity and average fuel consumption figures. Also, there is no information available on the production of wood chips from logging residues outside the national forests, so the ratio between logging and the preparation of logging residues, as it is in JSC "Latvia's state forests", is used to characterize it, while Forest Resources Monitoring data on logging outside forest lands in the previous five years.

Losses of forest biofuel in the production process are evaluated according to the data available in the scientific literature. According to Lindholm et al. (2010) loss of heat value during storage of logging residues and stumps can reach 20%. A similar result will be obtained in another study, where it was found that the loss of mass and thermal capacity when storing logging residues in a top stacker for 6-9 months is 7-20% (Thörnqvist, 1985).

In a review by Anerud et al. (2019) summarized the results of research conducted in the Nordic countries, where lower mass loss values were shown – 14% for deciduous trees after one summer storage, and 7% for coniferous trees after one summer storage. The research used the arithmetic mean of these two indicators – 11%, compared to the lowest calorific value of fresh wood. Reference value (standard value) of greenhouse gas emissions for the preparation (processing) of wood chips from forestry residues in accordance with the provisions of the regulations of Cabinet of Ministers No. 686 delivering fuel up to 500 km has 1.9 g CO_2 eq. MJ^{-1}. No standard value is given in regulations of Cabinet of Ministers No. 686, so the standard value of emissions from the processing of chips prepared from trunk wood is used for comparison. The lowest calorific value is accepted in the calculations in accordance with Annex 9 of the directive 2022/996 – 19 MJ kg^{-1}, but the conditional density of wood chips, converted to dry matter, is 155 kg m^{-3}. In the calculation of emissions caused by wood chipping, it is assumed that diesel-powered chippers and crushers are used.

Parameter e_{td} (transportation and sales emissions) calculations use the same methodical approach as for calculating the parameter e_{ec}. Equipment units included in the calculation – chip truck, log truck (for transporting firewood) and front loader in the intermediate storage. The calculation includes the transportation of wood chips and firewood from the roadside to the end use site, also evaluating the GHG emissions caused by the activities performed in the intermediate storage. Statistical data on the use of intermediate storage in the delivery of wood chips are not available, so this stage is not included in the calculation of total emissions.

Calculation methodology

The calculations were made using as a basis the methodology developed in the study "Development of equations for calculating GHG emissions generated in the process of production, storage and supply of energy wood" for the characterization of GHG emissions in the production and supply processes of forest biofuel (LVMI Silava, 2023).

The main assumptions characterizing the consumption of fuel, lubricants and other GHG emission-forming materials per unit of production and per unit of working time were prepared using the results of telephone surveys of entrepreneurs and information available in scientific literature. The information available in the scientific literature is also used for quality control. For example, based on the information provided by entrepreneurs, the heat carrier in air conditioning systems appeared as the biggest source of emissions, but when performing a logical control of the data and using the data available in the literature, this source of emissions turned out to be insignificant. The equipment units included in the study correspond to the assessment previously carried out in cooperation with JSC "Latvia's state forests", excluding the electric chipper from the list, as well as combining all types of chippers in the top stacker:

1. harvesters: compact harvester, medium harvester, large harvester, compact harvester with rivet head, medium harvester with rivet head, large harvester with rivet head, compact harvester equipped with chains, medium class harvester equipped with chains, large harvester equipped with chains, compact crawler excavator, medium crawler excavator, large crawler excavator, gasoline chain saws;
2. forwarders: compact forwarder, medium forwarder, large forwarder, compact forwarder equipped with chains, intermediate forwarder equipped with chains, large forwarder equipped with chains;
3. chippers and crushers: a chipper in a top loader with a diesel engine and a chipper in a bottom loader with a diesel engine;
4. wood transport: log truck for transporting firewood, chip truck with semi-trailer, chip truck with 2 containers (chip trucks need to be calculated separately for transportation from intermediate storage);

5. equipment transport: trailer for moving compact class equipment, trailer for moving medium class equipment, trailer for moving large equipment;
6. front-end loader for loading wood chips in an intermediate stacker.

The questions asked in the survey are summarized Table 6.

Table 6. Parameters included in the technical assessment

Group	No.	Pointer	Comment
Fuel consumption		L per motor hour during working hours	Fuel consumption during operation or average fuel consumption if more precise data is not available
	1.	L per motor hour during idle time	Recommended indicator to characterize fuel consumption during engine idling, not usable if29. row shows the average fuel consumption. If the average fuel consumption is shown, the proportion of idle time should be indicated as 0%
	2.	L 100 km^{-1} (outside the city with cargo)	Average fuel consumption
	3.	L 100 km^{-1} (in the city with cargo)	Average fuel consumption, in addition, the calculator shows the proportion of the distance traveled in the city
	4.	L 100 km^{-1} (outside the city without load)	Average fuel consumption
	5.	L 100 km^{-1} (in the city without load)	Average fuel consumption
	6.	Regardless of the type of felling, L LV m^{-3}	Average fuel consumption figures for chipper, loader and chip conveyors
	7.	Regardless of the type of felling, kWh LV m^{-3}	Electricity consumption of the wood chipper in the bottom stacker
Consumption of lubricants and oil, filling of conditioners	8.	lubricants, g per engine hour	The average consumption of lubricants for the lubrication of the manipulator and other moving parts, converted to engine hours, does not indicate if bio-oil is used
	9.	transmission oil, g per engine hour	The average consumption of transmission (including hydraulic) oil, including regular maintenance and as a result of accidents converted to engine hours, does not indicate if bio-oil is used
	10.	motor oil, g (motor) per hour	The average engine oil consumption during regular maintenance is converted to engine hours; for a chainsaw, oil that is mixed with fuel
	11.	heat carrier in air conditioners, g per motor hour	Average consumption during breakdowns and regular maintenance
	12.	engine oil, g km^{-1}	For trucks, engine oil consumption is expressed per 1 km
	13.	chain oil in other cuttings, g m^{-3}	The consumption of chain oil for the preparation of round timber and firewood, including the chain saw, does not indicate if bio-oil is used
	14.	chain oil in maintenance cutting, g m^{-3}	The consumption of chain oil for the preparation of round timber and firewood, including the chain saw, does not indicate if bio-oil is used
	15.	chain oil in the main cutting, g m^{-3}	The consumption of chain oil for the preparation of round timber and firewood, including the chain saw, does not indicate if bio-oil is used
	16.	chain oil in other cuts, g LV m^{-3}	Chain oil consumption in logging when no round timber is produced
	17.	chain oil in the care chainsaw, g LV m^{-3}	Chain oil consumption in logging when no round timber is produced

Group	No.	Pointer	Comment
	18.	chain oil in the main cutting, g LV m^{-3}	Chain oil consumption in logging when no round timber is produced
Percentage distribution of load when producing forest biofuel, LV m^3, working hours or km per month	19.	January	Average workload per month according to the volume produced
	20.	February	
	21.	March	
	22.	April	
	23.	May	
	24.	June	
	25.	July	
	26.	August	
	27.	September	
	28.	October	
	29.	November	
	30.	December	
Movement of equipment	31.	The average distance of moving equipment in other fellings, km	The average distance of moving machinery with a trailer in one direction
	32.	The average distance of moving equipment in maintenance fellings, km	The average distance of moving machinery with a trailer in one direction
	33.	The average distance of moving equipment in restoration fellings, km	The average distance of moving machinery with a trailer in one direction
	34.	The average distance of moving the machinery, regardless of the felling, km	Average distance of chippers in one direction
	35.	Delivery distance in other fellings, m	Average delivery distance for yield and fuel consumption calculations
	36.	Delivery distance in maintenance cuttings, m	Average delivery distance for yield and fuel consumption calculations
	37.	Delivery distance in renewal fellings, m	Average delivery distance for yield and fuel consumption calculations
	38.	Moving equipment during the year in other fellings (times)	Number of trips per year for the calculation of emissions related to the movement of equipment
	39.	Moving equipment during the year in maintenance fellings (times)	Number of trips per year for the calculation of emissions related to the movement of equipment
	40.	Movement of machinery during the year in renewal fellings (times)	Number of trips per year for the calculation of emissions related to the movement of equipment
Productivity (per engine hour)	41.	logging residues in other fellings, LV m^3 h^{-1}	Average productivity indicators in delivery, indicated for harvesters and chainsaws only in the event that the preparation of logging residues increases fuel consumption
	42.	logging residues in maintenance felling, LV m^3 h^{-1}	Average productivity indicators in delivery, indicated for harvesters and chainsaws only in the event that the preparation of logging residues increases fuel consumption
	43.	logging residues in the main felling, LV m^3 h^{-1}	Average productivity indicators in delivery, indicated for harvesters and chainsaws only in the event that the preparation of logging residues increases fuel consumption
	44.	stumps in main felling, LV m^3 h^{-1}	Average productivity rates for stump digging and harvesting
	45.	firewood in other fellings, m^3 h^{-1}	Average productivity indicators for sawing and bringing

Group	No.	Pointer	Comment
	46.	firewood in maintenance felling, m^3 h^{-1}	Average productivity indicators for sawing and bringing
	47.	firewood in the main felling, m^3 h^{-1}	Average productivity indicators for sawing and bringing
	48.	wood chips, LV m^3 h^{-1}	Average productivity rates for chipping and chip handling
	49.	biomass, cuttings for young growth, LV m^3 h^{-1}	Average productivity indicators for sawing and bringing
	50.	biomass, in vegetation harvesting, LV m^3 h^{-1}	Average productivity indicators for sawing and bringing
	51.	biomass, in ditch tracks, LV m^3 h^{-1}	Average productivity indicators for sawing and bringing
Load size	52.	Forwarder of logging residues in other fellings, LV m^3	Average size of logging residue cargo
	53.	Logging residue forwarder in maintenance fellings, LV m^3	Average size of logging residue cargo
	54.	Logging residue forwarder in main felling, LV m^3	Average size of logging residue cargo
	55.	Biomass forwarder in juvenile care cuttings, LV m^3	Average size of a load of sawn, unpruned small trees
	56.	Biomass forwarder in vegetation harvesting, LV m^3	Average size of a load of sawn, unpruned small trees
	57.	Biomass forwarder in ditch tracks, LV m^3	Average size of a load of sawn, unpruned small trees
	58.	Timber forwarder in other fellings, m^3	Average load size of round timber (with bark) for firewood yield calculations
	59.	Timber forwarder in maintenance fellings, m^3	Average load size of round timber (with bark) for firewood yield calculations
	60.	Timber forwarder in renewal fellings, m^3	Average load size of round timber (with bark) for firewood yield calculations
	61.	Chipper, LV m^3	Chipper load size
	62.	Timber carrier, m^3	Chipper load size
Chip and timber transport (including downtime)	63.	Average chip transport distance, km	Chip delivery distance in one direction
	64.	Average firewood transportation distance, km	Firewood delivery distance in one direction
	65.	Chip conveyor loading time during chipping, min.	Chip conveyor filling time for chipper productivity and fuel consumption calculations
	66.	Filling the chip conveyor with a front loader, min.	Chip conveyor filling time in intermediate stacker for yield and fuel consumption calculations
	67.	Chip conveyor unloading, min.	Chipper unloading time for yield and fuel consumption calculations
	68.	Log carrier loading, min.	Loading time of the log truck in the top stacker for yield and fuel consumption calculations
	69.	Log carrier unloading, min.	Logger unloading time at the bottom stacker for yield and fuel consumption calculations

Mostly, entrepreneurs could provide answers about fuel consumption, but information about the use of other materials was incomplete and had to be sought in technical service manuals and scientific literature. We received the most complete information from AS "Latvijas valsts meži", as well as from cooperation partners Skogforsk in Sweden and Metsateho in Finland, which create similar databases for life cycle analysis projects.

Fuel emission factors are taken from the Intergovernmental Panel on Climate Change (IPCC) guidelines (Eggleston et al., 2006), separating road and off-road transport, including diesel and gasoline used for chipping. The emission factors of lubricants and various oils are taken from Latvia's national GHG inventory report (Ministry of Environmental Protection and Regional Development, 2022). The values used in the calculations are summarized Table 7.

Table 7. Characteristics and emission factors of fuels and lubricants

Fuel	The lowest heat value			Density		CO_2	CO_2 eq	CO_2	CH_4	N_2O
	MJ L^{-1}	MJ m^{-3}	MJ kg^{-1}	kg L^{-1}	kg m^{-3}	tons t^{-1}	g kWh^{-1}	tons TJ^{-1}	Kg TJ^{-1}	Kg TJ^{-1}
Gasoline	32.0	-	43.4	0.7	-	-	-	69.3	170.0	0.4
Diesel fuel in off-road transport	36.0	-	42.6	0.8	-	-	-	74.7	5.5	28.0
Diesel fuel in road transport	36.0	-	42.6	0.8	-	-	-	74.8	2.8	2.8
Lubricants	-	-	41.9	-	-	0.6	-	-	-	-
Transmission oil	-	-	39.5	1.0	-	0.6	-	-	-	-
Engine oil	39.2	-	39.5	1.0	-	0.6	-	-	-	-

Other assumptions used in the calculations are given in Table 8. The proportion of bio-additive in the summer months is 6.5% for diesel fuel and 9.5% for gasoline. This indicator can be scaled up to estimate the impact of partial or complete substitution of fossil fuels with biofuels on GHG emissions. The density of wood chips, as well as the calorific value of firewood, are taken from Cabinet of Ministers regulations No. 42 (Cabinet of Ministers, 2018). The lowest calorific value of wood chips is taken from Annex 9 of Directive 2022/996. Average conditional wood density, carbon content in wood, as well as methane (CH_4) and nitrous oxide (N_2O) emission equivalents are taken from Latvia's national GHG inventory report, which corresponds to the factors used in the Fourth Assessment Report of the Intergovernmental Climate Change Council (Ministry of Environmental Protection and Regional Development, 2021).

Table 8. Coefficients and conversion factors

No.	Indicator and unit of measure	Numerical value
•	Proportion of bio-additives in fuel in the summer months (diesel / petrol)	6.5% / 9.5%
1.	Volume and volume ratio of forest biofuel (LV m^3 m-3)	2.5
2.	The lowest calorific value of chips (GJ LV m-3)	2.9
3.	The lowest calorific value of firewood with 40% relative humidity (GJ LV m-3)	10.0
4.	Average wood density (tons m-3)	0.42
5.	Average carbon content of wood	50%
6.	Methane GHG equivalent	25.0
7.	Nitrous oxide GHG equivalent	298.0
8.	HFC134-A	1430.0

A separate set of equations is created for each operation (harvesting, delivery, chipping, export, transshipment), which will allow combining different operations in supply chains. The equations are created universally – the same for all types of equipment and working environments. The exception is the calculation of working hours for trailers that transport machinery.

For the calculation of consumption indicators, data on the average consumption of resources per engine hour or per distance travelled and factors affecting productivity, such as the distance of delivery or fuel delivery, are used. In addition, a simplified calculation was performed, which evaluates only GHG emissions related to fuel consumption.

To characterize the consumption of fuel and lubricants for those machinery units or items for which no information was obtained from the manufacturers, the calculation equations included in the forest machinery cost calculation calculator developed by Ackerman et al. (2014) were used, in which the consumption of various resources is evaluated as a percentage of production costs. Costs were converted into material quantities using material price information available on the Internet during the development of the calculator. Data from studies conducted in Latvia were used to characterize the firewood production process. In situations where data is not available, assumptions are used, for example, about the consumption of heat carriers in air conditioning systems, assuming that the system is filled with HFC134-A, the most used heat carrier in Latvia, at least 3 times during the life of the equipment. Main sources of information,

- compact class harvester (Lazdins, Snepsts, et al., 2021; Ligné et al., 2005; Zimelis, Lazdiņš, et al., 2017; Zimelis et al., 2020);
- middle-class harvesters (Conrad IV et al., 2013; di Fulvio et al., 2012; Miyata, 1980; Zimelis & Spalva, 2022);
- the large harvester (Bergström & Fulvio, 2014; Björheden, 2017; Kizha & Han, 2016; Miyata, 1980);
- compact class harvester with a rivet head (Ehlert & Pecenka, 2013; Lazdins, Snepsts, et al., 2021; Zimelis, Lazdiņš, et al., 2017; Zimelis, 2017b);
- middle-class harvester with a pin head (Lazdiņš & Thor, 2009);
- the large pinhead harvester (Heikkilä et al., 2007; Lazdiņš & Thor, 2009; Miyata, 1980; Nordfjell et al., 2010);
- compact class harvester with chains (Abbas et al., 2018; Lazdins, Snepsts, et al., 2021; Miyata, 1980; Zimelis et al., 2020; Zimelis, 2017a);
- mid-range harvester with chains (Conrad IV et al., 2013; di Fulvio et al., 2012; Miyata, 1980; Petaja et al., 2017);
- the large harvester with chains (Bergström & Fulvio, 2014; Björheden, 2017; Kizha & Han, 2016; Miyata, 1980);
- a compact-class crawler excavator (Cornelissen et al., 2007; Devlin & Klvač, 2014; Laitila & Väätäinen, 2021; Väätäinen et al., 2004);
- medium crawler excavator (Bergroth et al., 2006; Magagnotti et al., 2017; Miyata, 1980; Zimelis et al., 2016);
- the large crawler excavator (Bergroth et al., 2006; Magagnotti et al., 2017; Miyata, 1980; Zimelis et al., 2016);
- gasoline chain saw (Calvo et al., 2013; Liepiņš et al., 2015);
- stump extraction (Lazdāns et al., 2008a; Lazdiņš & Lazdiņa, 2009; Lazdiņš & Zimelis, 2012);
- compact class forwarder (Forest Research An agency of the Forestry Commission, 2000; Lazdins, Kaleja, et al., 2021; Lazdiņš et al., 2016);
- middle class forwarder (Eriksson & Lindroos, 2014; Lazdiņš & Gercāns, 2011; Lazdiņš & Thor, 2009; Petaja et al., 2017; Thor et al., 2006);
- big forwarder (Bergström, 2019; Ferreira et al., 2019; Miyata, 1980);
- the forwarder equipped with chains (Kaleja et al., 2015; Rozītis et al., 2017; Zimelis, Kalēja, et al., 2017);
- a stationary chipper with a diesel engine (Aman et al., 2012; Spinelli et al., 2019; Suardi et al., 2020);
- a trailer for moving machinery (Fernandez-Lacruz et al., 2020; Kalēja et al., 2017; Schnorf et al., 2021; Väätäinen et al., 2006, 2021);
- wood carrier for transporting firewood (Kalēja, 2014; Thor et al., 2006);
- chip truck with semi-trailer (Kalēja et al., 2017; Lazdiņš & Thor, 2009; Thor et al., 2006)
- chip truck with 2 containers (Kalēja et al., 2017; Kons, 2015; Lazdiņš & Thor, 2009; Thor et al., 2006);
- front loader (Lazdiņš & Von Hofsten, 2009; Lazdiņš & Zimelis, 2012; Makovskis, 2015).

It should be noted that the assumptions used may have been obtained in different logging conditions, creating a not always correct picture of the impact of various machinery units on GHG emissions, for example, large crawler excavators were tested in Finland for harvesting small tree growth under power lines, creating a possibly wrong picture of the effect of this machinery. unit inefficiency (for large emissions) in logging. Data on fuel consumption and performance-influencing indicators derived from research results should be gradually replaced by indicators from production or equations.

Compared to the standard values given in the Annex of the Directive 2018/2001 "Disaggregated standard values for biomass fuel/fuel", for example for the production of wood chips from logging residues, the GHG emission index calculated by the simplified calculator for the production of wood chips is lower (1.6 g CO_2 eq. MJ^{-1}) than in the directive given indicator (1.9 g CO_2 eq. MJ^{-1}), on the other hand, the emissions caused by the delivery of wood chips are significantly higher in the directive – respectively, 3.6 g CO_2 eq. MJ^{-1} and 0.4 g CO_2 equiv. MJ^{-1}. By increasing the chip delivery distance to 500 km (the minimum delivery distance range mentioned in the directive), the calculated GHG emissions for chip transport increase to only 2.7 g CO_2 eq MJ^{-1}, not exceeding the default values given in the directive, although this delivery distance in practice without using sea transport , is not realistic.

A study conducted in Latvia in 2004 stated that the productivity of operators in production conditions could be 30% lower than during trials, because the factors that negatively affect productivity are not eliminated, for example, increased priority for equipment repairs (Thor et al., 2006). One of the most important reasons for the difference in emissions is downtime during work, as well as non-standard situations, such as pulling out stuck equipment, which are not usually reflected in research results, as well as overly optimistic assumptions about cargo size. Therefore, it is important that the assumptions used in the calculations are gradually replaced by indicators characterizing the production conditions.

When calculating the GHG emissions caused by the preparation of wood chips from the vegetation of agricultural lands and ditch tracks, it is assumed that the biomass is brought to a distance of 528 m and the distance of firewood delivery to the consumer is 75 km. A summary of GHG emissions from biomass preparation and delivery is given in the felling of vegetation Table 8. The calculation includes a medium-class harvester with a rivet head (up to 20 tons), a medium-class forwarder (up to 15 tons), a wood chipper with a diesel engine in the top loader and a chip transporter with 2 containers. Rivet head harvesters are not the most popular technology for harvesting vegetation, but this solution is associated with the largest emissions in logging, so it was chosen as the most conservative approach. Biofuel sustainability calculation parameter eec is equal to 2.2 g CO2 eq. MJ^{-1} and parameter etd – 0.4 g CO_2 eq. MJ^{-1}. GHG emissions from fuel consumption account for 99% of total emissions.

Table 9. GHG emissions from the production of biofuel from stand trees in the main felling

The device	kg CO_2 eq. LV m-3	kg CO_2 eq. ton of CO_2	g CO_2 eq. MJ-1
Mid-range harvester with rivet head (up to 20 tons)	2.9	9.4	1.0
Medium class forwarder (up to 15 tons)	1.5	4.7	0.5
Chipper with a diesel engine in the top loader	2.0	6.6	0.7
Chip conveyor with 2 containers	1.3	4.2	0.4
In total	7.7	24.9	2.6

Summary of parameter e_c and e_{td} calculations

Parameters e_{ec} and e_{td} calculated by comparing the total biofuel produced (Table 10) with total GHG emissions in the process of production and supply of forest biofuel (Table 11). Biofuel production is assessed according to the methodology approved in the study by LVMI Silava (2023).

The average e_{ec} parameter in 2022 is **0.9 g CO_2 eq. MJ^{-1}**, the average e_{td} parameter is **0.7 g CO_2 eq. MJ^{-1}** (Table 12).

Table 10. Lower calorific value (TJ) of forest biofuel

Year	Firewood	Peels	Woodworking residues	Proportion of firewood, bark and woodworking residues from maintenance felling	Logging residues in the main felling	Harvesting vegetation	Stumps in the main felling	In total
2008	14448	8398	22598	0.26	2752	737	1.23	48934
2009	18227	9879	26399	0.26	3688	890	1.48	59084
2010	21151	12006	32283	0.26	5030	1077	1.48	71549
2011	26607	10100	29174	0.24	4023	1069	1.48	70975
2012	24603	9313	26816	0.24	3700	985	1.49	65418
2013	25883	9275	24042	0.25	3355	956	1.49	63514
2014	24978	11102	28656	0.24	4588	1060	0.88	70384
2015	25955	11364	29349	0.24	4715	1091	0.88	72474
2016	25984	12262	32845	0.27	4809	1160	0.88	77062
2017	24854	11729	31417	0.27	4600	1110	0.86	73711
2018	24214	11427	30608	0.27	4482	1081	0.87	71813
2019	24214	11427	30608	0.27	4482	1081	1.69	71814
2020	23208	11650	31228	0.26	4640	1081	1.75	71809
2021	22710	12079	32249	0.24	5016	1081	1.75	73137
2022	22710	12079	32249	0.24	5016	1081	1.4	73137

Table 11. Summary of GHG emissions in the preparation of forest biofuel (Gg CO_2 eq)

Fuel	Param.	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Logging residues	e_{ec}	3.3	4.4	6.0	4.8	4.4	4.0	5.5	5.7	5.8	5.5	5.4	5.4	5,6	6.0	6.0
	e_{td}	1.1	1.5	2.0	1.6	1.5	1.3	1.8	1.9	1.9	1.8	1.8	1.8	1.9	2.0	2.0
Firewood	e_{ec}	5.9	7.3	8.6	10.6	9.8	10.3	9.9	10.3	10.6	10.1	9.9	9.9	9.4	9.0	9.0
	e_{td}	5.8	7.3	8.5	10.6	9.8	10.4	10.0	10.4	10.4	9.9	9.7	9.7	9.3	9.1	9.1
Peels	e_{ec}	9.2	10.8	13.2	11.0	10.2	10.1	12.1	12.4	13.5	12.9	12.6	12.6	12.8	13.2	13.2
	e_{td}	7.1	8.4	10.2	8.6	7.9	7.9	9.4	9.7	10.4	10.0	9.7	9.7	9.9	10.3	10.3
Woodworking residues	e_{ec}	24.9	29.0	35.5	31.9	29.3	26.3	31.3	32.0	36.2	34.6	33.7	33.7	34.4	35.2	35.2
	e_{td}	19.2	22.4	27.4	24.8	22.8	20.4	24.4	24.9	27.9	26.7	26.0	26.0	26.5	27.4	27.4
Strains	e_{ec}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	e_{td}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Harvesting vegetation	e_{ec}	1.6	2.0	2.4	2.4	2.2	2.1	2,3	2.4	2.6	2.4	2.4	2.4	2.4	2.4	2.4
	e_{td}	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4
All types of fuel	e_{ec}	44.9	53.6	65.6	60.6	55.8	52.9	61.1	62.7	68.6	65.6	63.9	63.9	64.5	65.9	65.9
	e_{td}	33.5	40.0	48.5	46.1	42.4	40.4	46.0	47.3	51.1	48.9	47.6	47.6	48.0	49.2	49.2

Table 12. Summary of GHG emissions in the preparation of forest biofuel (g CO_2 equiv. MJ^{-1})

Fuel	Param	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
All types of fuel on average	e_{ec}	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	e_{td}	0.7	0.7	0.7	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

Calculation of the parameters

Parameter e_l (annual emissions resulting from changes in land use due to changes in carbon accumulation) was calculated based on Forest Resources Monitoring and national GHG inventory data on wood harvesting in areas where land use change (deforestation and afforestation) took place in 2003 or later. The calculation uses the latest available GHG inventory report (Ministry of Environmental Protection and Regional Development, 2022), as well as calculations prepared for the 2024 GHG inventory report. The calculation of carbon stock was performed according to the methodology of the GHG inventory report, including the following carbon stores in the calculation: living biomass, dead wood, ground cover, ground cover and soil. Wood products are included in the calculation in areas where afforestation has been carried out, but in deforested areas the immediate oxidation method is used, ie all the carbon accumulated in the felled trees immediately turns into emissions. After 2002, no logging has been carried out in the forested areas, so there is no carbon input into the storage of wood products for now.

The calculation was made for total as well as average annual changes in carbon accumulation as a result of land use change in the period from 2003 to 2022 (within 20 years). Changes in carbon stock are applied to all wood obtained as a result of land use change in terms of carbon, as well as to biofuel obtained in areas where land use has been changed. The amount of biofuel is calculated assuming that the biomass of all branches and stumps, excluding production losses (50% for stumps and 30% for branches) is used as biofuel, while the proportion of wood and bark corresponds to the average proportion of wood and bark from the total volume of felled trees in the given year. Storage losses for branches and stumps will be described in the same way as for parameters eec and etc. Let's recalculate GHG emissions in energy units – g $CO_2 \cdot MJ^{-1}$, assuming that the calorific value of wood chips is 2945 MJ LV m^{-3}.

The calculation of the parameter el does not include N_2O emissions as a result of land use change, as well as emissions from such land use change situations where there is no harvesting of woody vegetation to transform forest land into other land use categories, for example the transformation of grasslands into arable land, because this land use change situation not related to biofuel production. The impact on emissions from organic soils in forested areas was evaluated by comparing GHG emissions from soil, maintaining the existing land use, as well as changing the land use, but in deforested areas, the total CO_2 emissions from the soil are included in the calculation.

As of 2003, the deforested area is 108 thousand. ha, on average 5.3 thousand per year. ha. Overgrown agricultural lands were mostly deforested and new construction areas were deforested in historical forest lands (Table 13).

Table 13. Deforested areas, 1000 ha

Deforested area	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Arable land	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	1.0	1.0	1.0	0.8
Lawn	2.9	2.9	2.9	2.9	2.9	2.9	2.7	2.7	2.7	2.7	2.7	0.6	0.6	0.6	0.6	0.6	2.6	2.6	2.6	1.8
Construction	0.7	0.7	0.7	0.7	0.7	0.7	1.5	1.5	1.5	1.5	1.5	1.9	1.9	1.9	1.9	1.9	2.2	2.2	2.2	2.1
Wetlands	1.4	1.4	1.4	1.4	1.4	1.4	1.8	1.8	1.8	1.8	1.8	0.4	0.4	0.4	0.4	0.4	2.0	2.0	2.0	1.3
Other lands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0
In total	5.0	5.0	5.0	5.0	5.0	5.0	6.4	6.4	6.4	6.4	6.4	3.2	3.2	3.2	3.2	3.2	7,8	7,8	7,8	6.0

Total CO_2 emissions from deforestation in the period from 2003 to 2022 are 14154 Gg CO_2, an average of 708 Gg CO_2 per year (Table 14).

Table 14. CO_2 emissions from deforestation, Gg CO_2 per year

Source of emissions	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CO_2 emissions from soil																				
Mineral soil	2	3	5	6	8	9	13	17	21	25	28	33	38	43	47	52	58	63	69	74
Organic soil	14	29	43	57	71	85	106	127	147	168	188	204	219	235	250	266	292	318	344	366
Understory and dead woody biomass																				
Ground cover	160	160	160	160	160	160	208	208	208	208	208	128	128	128	128	128	256	256	256	205
Dead wood	60	62	65	67	68	69	94	99	103	107	109	69	71	72	74	75	154	155	157	128
Living biomass																				
Above ground biomass	176	176	176	176	176	176	209	209	209	209	209	123	123	123	123	123	242	242	242	194
Below ground biomass	44	44	44	44	44	44	52	52	52	52	52	31	31	31	31	31	60	60	60	48
Total emissions from deforestation																				
All carbon stores	455	473	492	510	527	543	683	712	741	768	795	587	609	631	653	674	1062	1094	1128	1016

The total volume of logging in deforested areas corresponds to 3506 thousand. m^3, on average 175 thousand. m^3 (Table 15). The calculation of forest biofuel includes firewood, logging residues and stump wood.

Table 15. Logging and forest biofuel production in deforestation

Parameter	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Logging in deforestation, 1000 m^3																				
Logging	168	168	168	168	168	168	202	202	202	202	202	119	119	119	118	119	231	238	238	191
Round timber, pulpwood and logging residues in deforestation, 1000 m^3																				
Timber	76	79	77	75	77	79	92	94	88	87	82	49	49	49	48	48	91	94	106	85
Paper wood	64	62	64	64	63	63	78	76	70	70	80	46	46	46	46	46	88	91	92	74
Firewood	28	26	27	28	27	26	32	32	44	44	40	23	23	24	24	25	52	53	41	33
Logging residues	40	41	41	41	41	41	49	49	49	49	49	29	29	29	28	29	56	61	61	49
Stump wood	52	52	52	52	52	52	62	62	62	63	63	37	37	37	36	37	71	74	74	59

Assumptions for calculations are given in Table 16. Losses of stem biomass were taken in accordance with the results of research conducted in Latvia (Lazdāns et al., 2005, 2008b).

Table 16. Assumptions for the calculation of the lowest calorific value of forest biofuel

Pointer	Numerical value	Source of information
Bulk density of chips, kg dry weight. m^{-3}	155.00	Annex 9 of Regulation 2022/996
The lowest calorific value of chips, MJ dry kg^{-1}	19.00	Rules of the MK No. 42 (25.01.2018)
Production losses of logging residues	30.0%	Lazdāns et al., 2005
Stump wood production losses	50.0%	Lazdāns et al., 2008
The lowest calorific value of firewood (with 40% relative humidity), MJ m^{-3}	10.00	Rules of the MK No. 42 (25.01.2018)
Volume and volume ratio of forest biofuel (LV m^3 m^{-3})	2.50	Rules of the MK No. 42 (25.01.2018)

The calorific value of the biofuel prepared in deforestation fellings is determined approximately, assuming that the crown part and roots are also used for the preparation of biofuel. The total lower calorific value of forest biofuel prepared from 2003 to 2022 is 60.9 TJ, an average of 3.1 TJ yr^{-1} (Table 17).

Table 17. Lower calorific value (TJ) of forest biofuel obtained from deforestation

Type of fuel	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Firewood	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.3	0.5	0.5	0.4	0.3
Logging residues	1.3	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.0	1.0	1.0	0.9	1.0	1.9	2.0	2.0	1.6
Stump wood	1,2	1,2	1,2	1,2	1,2	1,2	1.5	1.5	1.5	1.5	1.5	0.9	0.9	0.9	0.9	0.9	1.7	1.8	1.8	1.4
In total	2.8	2.8	2.9	2.9	2.9	2.9	3,4	3,4	3.6	3.6	3.5	2.1	2.1	2.1	2.0	2.1	4.1	4.3	4.2	3,4

Afforestation partially offsets CO_2 emissions from deforestation. In the period from 2003 to 2022, the forested area is 155 thousand. ha, on average 8 thousand ha per year. Mostly wooded perennial grasslands (Table 18)

Table 18. Forested area since 2003, 1000 ha

Original land use	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Arable land	1.6	1.6	1.6	1.6	1.6	1.6	3.3	3.3	3.3	3.3	3.3	0.3	0.3	0.3	0.3	0.3	1.1	1.1	1.1	0.8
Lawn	1.4	1.4	1.4	1.4	1.4	1.4	5.5	5.5	5.5	5.5	5.5	1.3	1.3	1.3	1.3	1.3	11.4	11.4	11.4	7.3
Construction	1.9	1.9	1.9	1.9	1.9	1.9	0.9	0.9	0.9	0.9	0.9	0.1	0.1	0.1	0.1	0.1	1.5	1.5	1.5	0.9
Wetland	0.4	0.4	0.4	0.4	0.4	0.4	1,2	1,2	1,2	1,2	1,2	0.3	0.3	0.3	0.3	0.3	2,3	2,3	2,3	1.5
Other lands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
In total	5.2	5.2	5.2	5.2	5.2	5.2	10.8	10.8	10.8	10.8	10.8	1.9	1.9	1.9	1.9	1.9	16.4	16.4	16.4	10.6

The reduction of CO_2 emissions consists of changes in the carbon accumulation in non-living ground cover, ground cover plants, living and non-living tree biomass (Table 19). Total CO_2 emission reduction in the period from 2003 to 2022 as a result of afforestation corresponds to 3442 Gg CO_2, an average of 172 Gg CO_2.

Table 19. CO_2 sequestration and replaced emissions in forested areas

Source	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021		2022
CO2 sequestration in soil																					
Mineral soil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
Organic soil	-5.6	-6.2	-6.2	-6.2	-6.2	-6.2	-6.2	-6.4	-6.4	-6.4	-6.4	-6.4	-6.4	-6.4	-6.5	-6.6	-7.1	-7.7	-8.3		-8.7
in total	-5.6	-6.2	-6.2	-6.2	-6.2	-6.2	-6.2	-6.4	-6.4	-6.4	-6.4	-6.4	-6.4	-6.4	-6.5	-6.6	-7.1	-7.7	-8.3		-8.7
CO2 emissions from organic soils in grasslands and arable lands, maintaining the existing land use																					
Grasslands	0.0	2.2	2.2	2.2	2.2	2.2	2.2	2.8	2.8	2.8	2.8	2.8	2.8	3.2	3.6	3.9	7.7	11.5	15.3		17.8
Arable land	0.0	2.8	2.8	2.8	2.8	2.8	2.8	3.2	3.2	3.2	3.2	3.2	3.2	3.3	3,4	3.5	3.9	4.3	4.7		4.9
In total	0.0	5.0	5.0	5.0	5.0	5.0	5.0	6.0	6.0	6.0	6.0	6.0	6.0	6.5	6.9	7.4	11.6	15.8	20.0		22.7
Reduction of CO2 emissions from organic soils																					
In total	-5.6	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	0.0	0.5	0.9	4.5	8.1	11.7		14.0
CO2 sequestration in ground cover and dead wood																					
Ground cover	27.9	29.5	31.0	32.6	34.1	35.7	38.9	42.1	45.3	48.5	51.7	52.3	52.8	53.4	54.0	54.5	59.4	64.2	69.1		72.2
Dead wood	40.7	42.9	45.2	47.5	49.7	52.0	56.6	61.3	66.0	70.7	75.3	76.2	77.0	77.8	78.6	79.5	86.5	93.6	100.7		105.3
CO2 sequestration in living biomass																					
Above ground biomass	24.0	28.0	32.3	36.9	41.9	47.2	52.2	39.4	43.2	47.3	51.9	56.5	61.5	58.1	55.4	50.9	43.2	35.0	32.7		31.8
Below ground biomass	6.0	7.0	8.1	9.2	10.5	11.8	13.0	9.8	10.7	11.8	12.9	14.0	15.3	14.4	13.8	12.7	10.8	8.7	8.1		7.9
All carbon stores	92.9	106.1	115.3	125.0	135.0	145.4	159.4	152.2	164.8	177.9	191.5	198.6	206.2	203.8	202.2	198.5	204.4	209.6	222.3		231.2

Total CO_2 emissions as a result of land use change in the period from 2003 to 2022 is 10714 Gg CO_2, on average 536 Gg CO_2. Compared to the total biofuel prepared in deforestation, CO_2 emissions from land use change correspond to an average of 175 kg CO_2 MJ^{-1}.

Comparing the CO_2 emissions caused by land use change with the total biofuel consumed in Latvia, the average CO_2 emissions in 2003-2022. corresponds to 9.0 g CO_2 MJ^{-1} yr^{-1}.

The assessment of forest biofuel obtained in Latvia was carried out in 2021 (Lazdiņš, Makovskis, et al., 2021), characterizing the total GHG emissions in the process of production and consumption of forest biofuel. Compared to the data obtained in this study on the lowest calorific value of forest biofuel produced from raw materials obtained in Latvia, the average average CO_2 emissions in 2003-2022 corresponds to 8.0 g CO_2 MJ^{-1} yr^{-1}.

Calculation of e_{ec} and e_{td} sustainability parameters in shelter belts

Sustainability parameters are estimated assuming that all biomass produced in shelter belts is used as biofuel. It is assumed that the biomass is brought to a distance of 528 m and the distance of firewood delivery to the consumer is 75 km (the same values as at the national level biofuel assessment). A summary of GHG emissions from biomass preparation and delivery is given in Table 20. The calculation includes a medium-class harvester with a rivet head (up to 20 tons), a medium-class forwarder (up to 15 tons), a wood chipper with a diesel engine in the top loader and a chip transporter with 2 containers. Rivet head harvesters are not the most popular technology for harvesting vegetation, but this solution is associated with the largest emissions in logging, so it was chosen as the most conservative approach. Biofuel sustainability calculation parameter e_{ec} is equal to 2.2 g CO_2 eq. MJ^{-1} and parameter e_{td} – 0.4 g CO_2 eq. MJ^{-1}. GHG emissions from fuel consumption account for 99% of total emissions.

Table 20. GHG emissions from the production of biofuel from stand trees in the main felling

The device	kg CO_2 eq. LV m^{-3}	kg CO_2 eq. ton of CO_2	g CO_2 eq. MJ^{-1}
Mid-range harvester with rivet head (up to 20 tons)	2.9	9.4	1.0
Medium class forwarder (up to 15 tons)	1.5	4.7	0.5
Chipper with a diesel engine in the top loader	2.0	6.6	0.7
Chip conveyor with 2 containers	1.3	4.2	0.4
In total	7.7	24.9	2.6

Together with land use change related emissions the biofuel production emissions in shelter belts are 10.6 g CO_2 MJ^{-1}. Average emissions of biofuel production and delivery at national level is 9.6 g CO_2 MJ^{-1}. Smaller emissions are mainly associated with chosen harvesting technology – if stem wood is used as logs and pulpwood, the net emissions due to biofuel production in shelter belts would be smaller than the average national values due to higher productivity in shelter belts. The majority of emissions is associated with land use changes, and this issue can be solved only by afforestation of agricultural lands, particularly, organic soils to reduce GHG emissions due to deforestation.

Conclusions

1. Forest biofuel production in shelter belts conforms with the requirements of voluntary carbon trading platforms, including Verra Certified Carbon Standard and Golden Standard and can be implemented as measures within the scope of these instruments, providing at least the same rate of removals as conventional afforestation. However, methodology for implementation and monitoring of this measure needs to be approved by the above-mentioned commercial platforms.
2. European scale carbon trading platform is still at an early development stage; however, we did not find any nature conservation or agriculture related policies, which could hamper implementation of this measure within the scope of the European common carbon trading platform.
3. Net reduction potential of shelter belts in Latvia assuming 20 year-long rotation cycle is about 800 tons of CO_2 ha^{-1}(40 tons of CO_2 ha^{-1} yr^{-1}). Overall in 30 years this measure can provide 35 million tons of CO_2 eq., if 44000 ha of shelter belts are established. The cost of reducing GHG emissions with a

10% discount rate at the end of the first cycle in the 21st year is € 0.7 ton^{-1} CO_2. Additional costs may be proposed by farmers as not acquired profit, since areas proposed for establishment of shelter belts can be used as conventional croplands and grasslands.

4. Sustainability indicators of forest biofuel produced in shelter belts are slightly bigger than the average national indicators; however, they can be significantly smaller than the average if logwood and pulpwood is produced from tree trunks; therefore it is important to adopt management so to increase proportion of valuable logs in the output.

Literature

1. Abbas, D., Di Fulvio, F., & Spinelli, R. (2018). European and United States perspectives on forest operations in environmentally sensitive areas. *Scandinavian Journal of Forest Research*, *33*(2), 188–201. https://doi.org/10.1080/02827581.2017.1338355
2. Ackerman, P., Belbo, H., Eliasson, L., de Jong, A., Lazdins, A., & Lyons, J. (2014). The COST model for calculation of forest operations costs. *International Journal of Forest Engineering*, *25*(1), 75–81. https://doi.org/10.1080/14942119.2014.903711
3. Aman, A. L., Baker, S. A., & Greene, W. D. (2012). Productivity and Product Quality Measures for Chippers and Grinders on Operational Southern US Timber Harvests. *International Journal of Forest Engineering*, *22*(2). http://journals.hil.unb.ca/index.php/IJFE/article/view/19405
4. Anerud, E., Krigstin, S., Routa, J., Brännström, H., Arshadi, M., Helmeste, C., Bergström, D., & Egnell, G. (2019). *Dry matter losses during biomass storage. Measures to minimize feedstock degradation* (Task 43: 2019: xx; p. 45). IEA Bioenergy. https://www.ieabioenergy.com/wp-content/uploads/2020/01/EIA-Dry-Matter-Loss_Final.pdf
5. Bārdulis, A., Ivavons, J., Bārdule, A., Lazdiņa, D., Purviņa, D., Butlers, A., & Lazdiņš, A. (2022). Assessment of Agricultural Areas Suitable for Agroforestry in Latvia. *Land*, *11*(1873), 18. https://doi.org/10.3390/land11101873
6. Bergroth, J., Palander, T., & Kärhä, K. (2006). Excavator-based harvesters in wood cutting operations in Finland. *Forestry Studies\textbarMetsanduslikud Uurimused*, *45*, 74–88.
7. Bergström, D. (2019). Cost Analysis of Innovative Biomass Harvesting Systems for Young Dense Thinnings. *Croatian Journal of Forest Engineering*, *40*(2), 221–230. https://doi.org/10/gf7s37
8. Bergström, D., & Fulvio, F. D. (2014). Comparison of the cost and energy efficiencies of present and future biomass supply systems for young dense forests. *Scandinavian Journal of Forest Research*, *29*(8), 793–812. https://doi.org/10/f3p67t
9. Björheden, R. (2017). Development of bioenergy from forest biomass—A case study of Sweden and Finland. *Croatian Journal of Forest Engineering : Journal for Theory and Application of Forestry Engineering*, *38*(2), 259–268.
10. Calvo, A., Manzone, M., & Spinelli, R. (2013). Long Term Repair and Maintenance Cost of some Professional Chainsaws. *Croat. j. for. Eng.*, *34(2013)*(2), 265–272.
11. Christen, B., & Dalgaard, T. (2013). Buffers for biomass production in temperate European agriculture: A review and synthesis on function, ecosystem services and implementation. *Biomass and Bioenergy*, *55*, 53–67. https://doi.org/10/f4587f
12. Conrad IV, J. L., Bolding, M. C., Aust, W. M., Smith, R. L., & Horcher, A. (2013). Harvesting productivity and costs when utilizing energywood from pine plantations of the southern Coastal Plain USA. *Biomass and Bioenergy*, *52*, 85–95. https://doi.org/10.1016/j.biombioe.2013.02.038
13. Cornelissen, J. H. C., van Bodegom, P. M., Aerts, R., Callaghan, T. V., van Logtestijn, R. S. P., Alatalo, J., Stuart Chapin, F., Gerdol, R., Gudmundsson, J., Gwynn-Jones, D., Hartley, A. E., Hik, D. S., Hofgaard, A., Jónsdóttir, I. S., Karlsson, S., Klein, J. A., Laundre, J., Magnusson, B., Michelsen, A., … M.O.L. Team†. (2007). Global negative vegetation feedback to climate warming responses of leaf litter decomposition rates in cold biomes. *Ecology Letters*, *10*(7), 619–627. https://doi.org/10.1111/j.1461-0248.2007.01051.x
14. Devlin, G., & Klvač, R. (2014). How Technology Can Improve the Efficiency of Excavator-Based Cable Harvesting for Potential Biomass Extraction—A Woody Productivity Resource and Cost Analysis for Ireland. *Energies*, *7*(12), Article 12. https://doi.org/10.3390/en7128374

15. di Fulvio, F., Bergström, D., Kons, K., & Nordfjell, T. (2012). Productivity and Profitability of Forest Machines in the Harvesting of Normal and Overgrown Willow Plantations. *Croat. j. for. Eng.*, *33*(1), 25–37.
16. Ehlert, D., & Pecenka, R. (2013). Harvesters for short rotation coppice: Current status and new solutions. *International Journal of Forest Engineering*, *24*(3), 170–182. https://doi.org/10.1080/14942119.2013.852390
17. Eriksson, M., & Lindroos, O. (2014). Productivity of harvesters and forwarders in CTL operations in northern Sweden based on large follow-up datasets. *International Journal of Forest Engineering*, *25*(3), 179–200. https://doi.org/10.1080/14942119.2014.974309
18. Fernandez-Lacruz, R., Eriksson, A., & Bergström, D. (2020). Simulation-Based Cost Analysis of Industrial Supply of Chips from Logging Residues and Small-Diameter Trees. *Forests*, *11*(1), Article 1. https://doi.org/10.3390/f11010001
19. Ferreira, F. de A. C., Freitas, L. C. de, Leite, E. da S., & Barros, A. P. da S. (2019). Geotechnology as a Planning Tool in the Determination of Forest Extraction Costs. *Floresta e Ambiente*, *26*(4), e20170879. https://doi.org/10.1590/2179-8087.087917
20. Forest Research An agency of the Forestry Commission. (2000). *The Vimek 606D mini-forwarder* (1400A/12/00 7.12a; p. 4). https://www.forestry.gov.uk/pdf/ODW712a.pdf/$FILE/ODW712a.pdf
21. Heikkilä, J., Sirén, M., & Äijälä, ja O. (2007). Management alternatives of energy wood thinning stands. *Biomass and Bioenergy*, *31*(5), 255–266. https://doi.org/10.1016/j.biombioe.2007.01.013
22. Kalēja, S. (2014). *Evaluation of impact of assortments' structure on productivity of Timbear harvester in early thinning*. Nordic Baltic Conference OSCAR14, Kvinsta, Sweden.
23. Kaleja, S., Lazdins, A., & Prindulis, U. (2015). *Evaluation of impact of different types of tracks on productivity and cost of differently equipped forwarders in thinning*. 41–43.
24. Kalēja, S., Lazdiņš, A., Zimelis, A., & Spalva, G. (2017). Model for cost calculation and sensitivity analysis of forest operations. *Agronomy Research*, *16*(5), 2068–2078. Scopus. https://doi.org/10.15159/AR.18.207
25. Kizha, A. R., & Han, H.-S. (2016). Processing and sorting forest residues: Cost, productivity and managerial impacts. *Biomass and Bioenergy*, *93*, 97–106. https://doi.org/10.1016/j.biombioe.2016.06.021
26. Kons, K. (2015). *Forest biomass terminal properties and activities* [Licentiate Thesis]. Swedish University of Agricultural Sciences.
27. Laitila, J., & Väätäinen, K. (2021). Productivity and cost of harvesting overgrowth brushwood from roadsides and field edges. *International Journal of Forest Engineering*, *32*(2), 140–154. https://doi.org/10.1080/14942119.2021.1903790
28. Lazdāns, V., Lazdiņš, A., & Graudums, M. (2005). *Cirsmu atlieku izmantošana energoapgādē – resursu, tehnoloģiju, ekonomiskās un ietekmes uz vidi novērtējums (Pārskats par meža attīstības fonda pasūtītā pētījuma izpildi)*. LVMI Silava.
29. Lazdāns, V., Lazdiņš, A., & Zimelis, A. (2008a). *Celmu izstrādes tehnoloģijas enerģētiskās koksnes ražošanai*. LVMI Silava.
30. Lazdāns, V., Lazdiņš, A., & Zimelis, A. (2008b). *Meža infrastruktūras objektu kopšanā iegūstamo enerģētiskās koksnes resursu aprēķinu metodikas izstrāde (Pārskats par Meža attīstības fonda pasūtītā pētījuma izpildi)*. LVMI Silava.
31. Lazdiņš, A., & Gercāns, J. (2011). *Productivity of forwarding depending from driving conditions*.
32. Lazdins, A., Kaleja, S., Zimelis, A., Spalva, G., & Bardulis, A. (2021). Productivity and carbon dioxide (CO2) emissions of compact class Vimek 404 T5 harvester in thinning of young birch stands in afforested cropland. *Engineering for Rural Development*, 780–785. https://doi.org/10.22616/ERDev.2021.20.TF173
33. Lazdiņš, A., & Lazdiņa, D. (2009). *Sustainable forest biomass resources for biofuel production in Latvia*. http://www.unece.org/fileadmin/DAM/timber/meetings/20090915/20Lazdins.pdf
34. Lazdiņš, A., Makovskis, K., & Kalēja, S. (2021). *Resources and use of forest biofuel in light of implementation of the national and common European climate change mitigation targets* (Draft 2021-05–1; p. 97). LSFRI Silava. https://drive.google.com/file/d/1w-N-UGwhlXLJ0HQm1M2XqORUMI1gb7-D/view?usp=sharing

35. Lazdiņš, A., Prindulis, U., Kalēja, S., Daugaviete, M., & Zimelis, A. (2016). Productivity of Vimek 404 T5 harvester and Vimek 610 forwarder in early thinning. *Agronomy Research*, *14*(2), 475–484. Scopus.
36. Lazdiņš, A., Sietiņa, I., Lazdiņa, D., & Butlers, A. (2021). *Report and equations for classification of growth conditions in the "buffer zones" including catalogue of growth conditions and suitable plant communities* (Final 2021.1.2.1; Evaluation of Growth Potential of Fast Growing Tree Species Suitable for Transformation of Buffer Zones into "Biomass Factories", p. 21). Latvia State Forest Research Institute 'Silava'.
37. Lazdins, A., Snepsts, G., Butlers, A., Purvina, D., Zvaigzne, Z. A., & Licite, I. (2021). *Evaluation of middle term Greenhouse Gas (GHG) mitigation potential of birch plantations with mineral and organic soils*. 32–37. https://doi.org/10.22616/ERDev.2021.20.TF005
38. Lazdiņš, A., & Thor, M. (2009). Bioenergy from pre-commercial thinning, forest infrastructure and undergrowth – resources, productivity and costs. *Annual 15th International Scientific Conference Proceedings*, 147–154.
39. Lazdiņš, A., & Von Hofsten, H. (2009). Technical and environmental issues of stump harvesting for biofuel production in Latvia. *Annual 15th International Scientific Conference Proceedings*, 155–162.
40. Lazdiņš, A., & Zimelis, A. (2012). Productivity of stump lifting head MCR-500. *Mežzinātne. Special Issue. Abstracts for International Conferences Organized by LSFRI Silava in Cooperation with SNS and IUFRO*, *25 (58)*, 42–45.
41. Liepiņš, K., Lazdiņš, A., Liepiņš, J., & Prindulis, U. (2015). Productivity and Cost-Effectiveness of Mechanized and Motor-Manual Harvesting of Grey Alder (Alnus incana (L.) Moench): A Case Study in Latvia. *Small-Scale Forestry*, 1–14. https://doi.org/10.1007/s11842-015-9302-1
42. Ligné, D., Nordfjell, T., & Karlsson, A. (2005). New Techniques For Pre-Commercial Thinning – Time Consumption and Tree Damage Parameters. *International Journal of Forest Engineering*, *16*(2), 89–99. https://doi.org/10.1080/14942119.2005.10702518
43. Lindholm, E.-L., Berg, S., & Hansson, P.-A. (2010). Energy efficiency and the environmental impact of harvesting stumps and logging residues. *European Journal of Forest Research*, *129*(6), 1223–1235. https://doi.org/10.1007/s10342-010-0412-1
44. LVMI Silava. (2023). *Enerģētiskās koksnes ražošanas, uzglabāšanas un piegādes procesā radīto SEG emisiju aprēķina vienādojumu izstrāde* (2022-02–01; 5-5.5.1_001p_101_22_41, p. 50).
45. Magagnotti, N., Pari, L., & Spinelli, R. (2017). Use, Utilization, Productivity and Fuel Consumption of Purpose-Built and Excavator-Based Harvesters and Processors in Italy. *Forests*, *8*(12), 485. https://doi.org/10.3390/f8120485
46. Makovskis, K. (2015). *Productivity and cost of stump extraction in forest stands heavily affected by root rot*. Knowledge Based Forest Sector, Riga.
47. Melniks, R., Sietina, I., & Lazdins, A. (2022). Methodology for assessment of area and properties of farmlands suitable for establishment of shelter belts. *Engineering for Rural Development*, 812–817. https://doi.org/10.22616/ERDev.2022.21.TF248
48. Ministru Kabinets. (2018, January 25). Siltumnīcefekta gāzu emisiju aprēķina metodika, noteikumi Nr. 42 (Methodology for calculation of greenhouse gas emissions, regulations no. 42). *Latvijas Vēstnesis*, *18*. https://likumi.lv/ta/id/296651-siltumnicefekta-gazu-emisiju-aprekina-metodika
49. Ministry of Environmental Protection and Regional Development. (2021). *Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990 – 2019* (p. 545). Ministry of Environmental Protection and Regional Development of the Republic of Latvia. https://unfccc.int/documents/271530
50. Ministry of Environmental Protection and Regional Development. (2022). *Latvia's National Inventory Report Submission under UNFCCC and the Kyoto protocol Common Reporting Formats (CRF) 1990 – 2020* (p. 545). Ministry of Environmental Protection and Regional Development of the Republic of Latvia.
51. Miyata, E. S. (1980). *Determining fixed and operating costs of logging equipment* (General Technical Report NC-55; USDA Forest Service, p. 20). Forest Service, U.S. Department of Agriculture. https://www.fs.usda.gov/treesearch/pubs/10120

52. Nordfjell, T., Björheden, R., Thor, M., & Wästerlund, I. (2010). *Changes in technical performance, mechanical availability and prices of machines used in forest operations in Sweden from 1985 to 2010*. *25*. http://dx.doi.org/10.1080/02827581.2010.498385
53. Petaja, G., Butlers, A., Okmanis, M., & Zimelis, A. (2017). Estimation of productivity and prime cost of Logset 5HP GT harvester in thinning. *Proceedings of the 8th International Scientific Conference Rural Development 2017, In press*. https://doi.org/10.15544/RD.2017.175
54. Rozītis, G., Zimelis, A., & Lazdiņš, A. (2017). Evaluation of productivity and impact on soil of tracked ProSilva F2/2 forwarder in forest thinning. *Research for Rural Development*, *1*, 94–100. https://doi.org/10.22616/rrd.23.2017.014
55. Schnorf, V., Trutnevyte, E., Bowman, G., & Burg, V. (2021). Biomass transport for energy: Cost, energy and CO2 performance of forest wood and manure transport chains in Switzerland. *Journal of Cleaner Production*, *293*, 125971. https://doi.org/10.1016/j.jclepro.2021.125971
56. Spinelli, R., Eliasson, L., & Magagnotti, N. (2019). Determining the repair and maintenance cost of wood chippers. *Biomass and Bioenergy*, *122*, 202–210. https://doi.org/10.1016/j.biombioe.2019.01.024
57. Styles, D., Börjesson, P., D'Hertefeldt, T., Birkhofer, K., Dauber, J., Adams, P., Patil, S., Pagella, T., Pettersson, L. B., Peck, P., Vaneeckhaute, C., & Rosenqvist, H. (2016). Climate regulation, energy provisioning and water purification: Quantifying ecosystem service delivery of bioenergy willow grown on riparian buffer zones using life cycle assessment. *Ambio*, *45*(8), 872–884. https://doi.org/10/f9r79r
58. Suardi, A., Latterini, F., Alfano, V., Palmieri, N., Bergonzoli, S., & Pari, L. (2020). Analysis of the Work Productivity and Costs of a Stationary Chipper Applied to the Harvesting of Olive Tree Pruning for Bio-Energy Production. *Energies*, *13*(6), 1359. https://doi.org/10.3390/en13061359
59. Thor, M., Von Hofsten, H., Lundström, H., Lazdāns, V., & Lazdiņš, A. (2006). *Extraction of logging residues at LVM* (p. 36). AS Latvijas valsts meži.
60. Thörnqvist, T. (1985). Drying and storage of forest residues for energy production. *Biomass*, *7*(2), 125–134. https://doi.org/10.1016/0144-4565(85)90038-1
61. Väätäinen, K., Asikainen, A., Sikanen, L., & Ala-Fossi. (2006). The cost effect of forest machine relocations on logging costs in Finland. *Forestry Studies|Metsanduslikud Uurimused*, *45*, 135–141.
62. Väätäinen, K., Hyvönen, P., Kankaanhuhta, V., Laitila, J., & Hirvelä, H. (2021). The Impact of Fleet Size, Harvesting Site Reserve, and Timing of Machine Relocations on the Performance Indicators of Mechanized CTL Harvesting in Finland. *Forests*, *12*(10), Article 10. https://doi.org/10.3390/f12101328
63. Väätäinen, K., Sikanen, L., & Asikainen, A. (2004). Feasibility of Excavator-Based Harvester in Thinnings of Peatland Forests. *International Journal of Forest Engineering*, *15*(2). http://journals.hil.unb.ca/index.php/IJFE/article/view/9855
64. Zimelis, A. (2017a, April 27). *Productivity of Vimek 404 T5 harvester in forest thinning in Latvia*. LOGGING INDUSTRY: PROBLEMS AND SOLUTIONS, Minsk.
65. Zimelis, A. (2017b, April 27). *Productivity of Vimek BioCombi harwarder in early thinning in Latvia*. LOGGING INDUSTRY: PROBLEMS AND SOLUTIONS, Minsk.
66. Zimelis, A., Kaleja, S., & Ariko, S. (2020). *Evaluation of productivity and costs of Malwa forest machine in sanitary fellings in Latvia*. 61–65. https://doi.org/10.22616/rrd.26.2020.009
67. Zimelis, A., Kalēja, S., Lazdiņš, A., Štāls, T., & Saule, G. (2017). *Atbalsta ķēžu pētījums (forwarder track comparison)* (2017–21; Meža Darbu Mehanizācijas Un Meža Biokurināmā Pētījumu Programma, p. 28). Latvijas Valsts mežzinātnes institūts ''Silava''.
68. Zimelis, A., Lazdiņš, A., & Spalva, G. (2017). Comparison of productivity of Vimek harvester in birch plantation and young coniferous stands. *Research for Rural Development*, *1*, 107–112.
69. Zimelis, A., Spalva, G., Saule, G., Daugaviete, M., & Lazdiņš, A. (2016). Productivity and cost of biofuel in ditch cleaning operations using tracked excavator based harvester. *Agronomy Research*, *14*(2), 579–589.