EU LIFE Programme project
"Demonstration of climate change mitigation potential of nutrients rich organic soils in Baltic States and Finland"

REPORT

ON IMPLEMENTATION OF THE PROJECT

DEMONSTRATION OF CLIMATE CHANGE MITIGATION MEASURES IN NUTRIENTS RICH DRAINED ORGANIC SOILS IN BALTIC STATES AND FINLAND

WORK PACKAGE
FILLING KNOWLEDGE GAPS ON GHG EMISSIONS FROM ORGANIC SOILS(C.1)
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"LIFE OrgBalt compiled the first regional Baltic/ Finnish GHG emission factors for managed nutrient-rich organic soils (current and former peatlands), which have been made available for the customary scientific review and further verification for national GHG inventories in the hemiboreal region in Finland and the Baltic countries. While the project analysed selected CCM measures for drained organic soils in agriculture and forestry and developed spatial models and tools, it also identified remaining knowledge gaps. To bridge the remaining limitations and fill the gaps, it is essential to continue GHG measurements and model development, as well to broaden and complete the scope of the evaluated CCM measures in the after-LIFE-project period, notably by including rewetting and restoration of peatlands that are currently considered to be among the most recommended CCM measures on drained peatlands in the EU. In addition, the developed Simulation and PPC models still include limited macroeconomic considerations and lack assessment of all environmental impacts. For all these reasons, these models should be used carefully in CCM strategy development for identification of gaps in climate neutrality transition policy and funding frameworks and need further optimization for broader applicability as decision-making tools."

SUMMARY

Catalogue of climate change mitigation (CCM) measures is aimed to summarize the data obtained in reference and demonstration sites within the scope of the LIFE OrgBalt project and the research data acquired in temperate region including socio-economic impact assessment, GHG emission factors and activity data elaborations within the project. Catalogue is linked to the elaborated modelling tools and contain instructions for application of CCM measures.

The data sources besides the project results used for the preparation of the catalogue are: SNS-120 project results (anthropogenic GHG emissions from organic forest soils and improved inventories and implications for sustainable management), LIFE REstore, Effect of clear-cut and thinning on forest carbon cycling and other regional projects.

Catalogue of CCM measures is aimed to be adopted among policy planners and incorporated into related policy documents and strategies.

The deliverable "Catalog of climate change mitigation actions" is prepared in two stages. In 2022 we elaborated interim report to set the structure and collate the project information. It contained the information on GHG mitigation potential based on literature studies and previous research as well as available socio-economic impact assessment data. During the second stage we elaborated report on the measures proved to be efficient during the implementation of the study and evaluation of the effect of the measures, as well as the socio-economic assessment of the measures. The report contain recommendations for implementation of the CCM measures and guidelines for adaptation of the proposed solutions.

It should be noted that not all of the study results are published and there still will be updates of the emission factors and other parameters affecting the modelling results. The project also highlighted uncertainty of the activity data – even in very shallow, well decomposed peat soils we observed significant carbon losses from soil in grasslands and arable lands. It is also crucial to mention that management activities, like crop selection and fertilization, can have significant effect on the soil carbon input, which can change the carbon turnover sign from negative to positive and vice versa.

ABBREVIATIONS

C = carbon

CH_4 = methane

CO_2 = carbon dioxide

CCM = climate change mitigation

EF = emission factor

GHG = greenhouse gas

GWT = groundwater table

IPCC = Intergovernmental Panel on Climate Change

LULUCF = land use, land-use change and forestry

N_2O = nitrous oxide

SOM = soil organic matter

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1. INTRODUCTION

During the initial project stage we evaluated several climate CCM measures successfully implemented in nutrient rich organic soils or having multiple scientific evidences of emissions reduction potential, while not tested in practice at large scale. We also evaluated several measures with potential effect with controversial information about the potential implementation potential or the awaited effect.

CCM actions evaluated in forest land included conventional afforestation considering shorter rotation; forested paludiculture – afforestation of grassland with black alder and birch; continuous forest cover as a forest regeneration method in spruce stands; strip or spot harvesting in pine stands (can be applied to other sun-lowing tree species too), improved forest regeneration methods with black alder without reconstruction of drainage systems, application of wood ash after commercial thinning in spruce stands, improved forest regeneration methods in coniferous tree stands with naturally wet organic soil, planting of black alder in riparian buffer zone in forest land. In agriculture land we evaluated the potential of agroforestry – fast growing trees and grass, conversion of cropland used for cereal production into grassland considering periodic ploughing, planting of fast growing species in riparian buffer zones around drainage systems, controlled drainage of grassland considering even groundwater level during the whole vegetation period, introduction of legumes in conventional farm crop rotation.

The project results proved efficiency of certain measures evaluated during the initial stage of the implementation. The transformation of arable land with organic soil into grassland can significantly reduce GHG emissions and it is least costly measure; however, it's effect is multiple times times smaller than the effect of afforestation. Afforestation of grasslands with following rewetting is another measure demonstrating significant mitigation potential; however, it is also associated with higher risk of natural disturbances. Remedial ditching is important measure, which have to be implemented during the regeneration stage to reduce the disturbance risk. However, this risk remains comparably high also during later stand development stages. Use of wood ash in a spruce and pine stands with drained organic soil after thinning is another efficient and fast acting measure ensuring significant additional CO_2 removals in living biomass during short period of time and having long-lasting risk-reduction effect. Agro-forestry measures, like plantation of woody plants in arable land with drained organic soil theoretically is the most efficient of the evaluated measures; however, it is also the most expensive and associated with bigger risk of natural disturbances due to drought and animal damages; therefore, plantations requires protection and more attention during the regeneration stage than the afforestation related measures. Planting of fast-growing tree species in shelter belts of drainage systems have similar CCM effect and provides additional pollution prevention and biodiversity related benefits; however, it is even more expensive and complicated in the implementation stage.

Above mentioned CCM measures can be recommended for the National climate and energy action plans and other support schemes to implement short term and long term climate neutrality targets. However, studies have to be continued, especially to evaluate potential risks and methods to avoid natural disturbances or increase the mitigation potential and to improve modelling methods.

However, not all of the evaluated CCM measures resulted in undoubted positive result. We did not observed in our study positive effect of the use of legumes in plant rotation in arable land with drained organic soil and controlled drainage in grassland with organic soil. In case of legumes the biggest shortcoming is actually insufficient data on carbon input into soil with different plant species. Slight changes in assumptions on the above- and below-ground biomass results in negative or positive effect of the measure. Therefore, biomass input data should be improved before recommendation or rejecting of this measure, as specifically dedicated to organic soils, because positive effect in agriculture sector is doubtfulness.

We did not observed also significant positive effect of strip or spot felling in a pine stands. This measures requires further investigations before recommendation for implementation in the national climate and energy programs, particularly, on changes of growth rate, since this method of forest regeneration is associated with increased side effect, potentially reducing growth rate and accumulation of CO_2 in living biomass. It may be compensated by growth of remaining trees and better moisture regime, but still there is insufficient amount of scientific evidences to recommend this measure.

Selective felling in spruce stands demonstrated positive effect on GHG emissions from soil; however, this effect can be neglected by the fact that logging area should be increased at least three times to acquire the same amount of wood, and cumulative emissions from such, extended area may be even bigger than from smaller clear-felling site. Additionally, selective felling is associated with the increased risk of natural disturbances, it makes impossible artificial regeneration, thus loosing breeding effect (15-20% of additional removals in living biomass) and it can contribute to negative selection by leaving weaker and removing stronger trees during felling. Strip or spot harvesting in spruce stands should be evaluated further to evaluate if the effect of the mitigation of emissions from soil is retained in the smaller, e.g. 0.5 ha, openings.

Forest regeneration with black alder or spruce in forest stands with naturally wet organic soils by planting trees on mounds and by establishing network of deep furrows (30-50 cm) to remove exceeding water from topsoil seems to be promising solutions, in spite they are associated with bigger risk of natural disturbances, e.g. periodic flooding and nutrient shortage. Proper management of risks is the key element for success during implementation of these measures. Further observations are necessary to evaluate the effect on soil GHG fluxes after regeneration. Additional efforts should be paid to elaborate spatial tool for selection of forest stands suitable for implementation of this measure and development of remedial drainage system and network of furrows.

Planting of black alder shelter belts in alluvial zones in areas with organic soil seems to be efficient forestry measure; however, selection of suitable areas may be more complicated than for other measures, particularly, because of management restrictions having potential negative effect on long term carbon storage in HWP and substitution effect. This measure also requires further investigation to evaluate effect of the soil GHG fluxes. However, this measure can be implemented as a part of artificial regeneration of forests with wet organic soils by planting black alder or birch in depressions, where probability of survival of coniferous trees is significantly smaller; thus this measure would also contribute to increase of biodiversity.

The most of the study results are still in the publishing stage and may be updated in future. We also realized that the activity data for different Baltic states are insufficient to evaluate country level implementation potential; therefore, this report contains per area unit estimates of the potential effect of certain measures; which can be extrapolated to the national level during further studies.

We used the same structure of the description of the measures as in the first stage report, so the changes in values and assumptions can be easily tracked.

2. RECOMMENDED CLIMATE CHANGE MITIGATION MEASURES

2.1 Climate change mitigation measures in forest land

Climate change mitigation in forests with organic soils is not straightforward. Forestry affects the environment in many different ways, depending on the type of forestry, the initial state of the forest and the climate. In general, forest management practices that increase carbon sequestration include:

- afforestation, reforestation and forest restoration;
- increase of tree cover through agroforestry, urban forestry and tree planting in rural landscapes;
- enhancement of forest carbon stocks (in both, biomass and soils) and sequestration capacity through the modification of forestry management practices.

High ground water tables (GWT) can be beneficial for maintaining the carbon stocks in organic soil. Over-drainage should always be avoided and it should be realized that groundwater level is dynamic and drops down in summer months due to evapotranspiration and infiltration. Although deepening the water table increases productivity, in Finland it is found that after the tree stand volume has exceeded 100–150 m^3 ha^{-1} forest can regulate groundwater level by itself (Sarkkola et al., 2010). After this threshold has been reached, the tree stand itself, through efficient transpiration, maintains sufficient drainage. Similar findings are published in Latvia demonstrating that restoration of drainage systems may not be necessary in healthy growing stands (Zālītis, 2008, 2012; Zālītis et al., 2010).

Drainage of forests on organic soils can lead to increase of carbon dioxide (CO_2) net emission from soil due to loss of peat. This emission can be compensated for by the increased tree growth. However, many drained peatlands have low tree growth due to nutrient limitations. Tree growth at these peatlands can be effectively increased by fertilization, but fertilization has been also found to increase decomposition rates. Ojanen et al. (2019) in the study in Finland concluded that fertilization of low-productive peatland forests has potential for climate change mitigation in the decadal time scale. The study revealed that the great increase in productivity due to fertilization leads to a long-term increase in tree stand CO_2 sink that clearly exceeds the increase in soil CO_2 net emissions. The effect of fertilization on CH_4 emissions was generally negligible. CH_4 emissions from ditches would also be reduced if ditches were cleaned in addition to fertilization. While fertilization may increase N mineralization through enhanced decomposition, also net primary production increases leading to increased N demand. Thus, fertilization does not seem to induce a risk of N_2O emissions (Ojanen et al., 2019).

Another option currently considered and studied is replacing the maintenance of drainage systems with fertilization by wood ash. The idea behind this is that the reduced tree growth rate under moderate or shallow-drained GWT may rather be due to low nutrient availability in the limited oxic soil layer than the wetness as such. Wood ash increases tree stand carbon sequestration and tree litter inputs to the soil, both being beneficial for the site carbon balance. If simultaneously the decomposition processes in the soil are not accelerated to the relatively high GWT, CCM is achieved. This measure is also proved as being very efficient also in Latvia (Champion et al., 2022; Neimane et al., 2021; Petaja et al., 2019).

2.1.1 Conventional afforestation considering intensified management of forest stands

Afforestation of organic soil in grassland and cropland is the most obvious restoration method dominating as natural succession in abandoned farmlands In Baltic states. The scope of this measure is to improve growth rate and resilience of forest stand, which would originate naturally after abandonment of organic soils previously used in agriculture. The description of this measure is provided in Table 1. The mitigation rate is calculated assuming that grassland is planted with spruce and drainage system is maintained to keep groundwater level around 30 cm below the ground surface. Duration of rotation – 60 years, assuming that the criteria for regenerative felling is average diameter of target trees. Shortening of rotation may increase the net removals if the output of HWP is increased and regeneration period, when regenerated forest stand is net source of emissions, is not increased. Additional effect can be accessed in case of afforestation of cropland and use of wood ash as a fertilizer. Continuous mitigation effect through several rotations can be accessed through use of selected planting material ensuring increase of growing stock by 10-20% every next rotation and by increase the resilience of forest stands.

Cumulative effect of the measure is shown in Figure 2. The effect of the measure is based on several studies implemented in Latvia and IPCC guidelines (Ali et al., 2024; Butlers et al., 2023; Butlers, Lazdiņš, et al., 2022; Butlers, Spalva, et al., 2022; Hiraishi et al., 2013; Lazdiņš et al., 2024; Vanags-Duka et al., 2022).

Table 1. Afforestation of organic soils

Objectives of the measure	Economic objective: to produce timber and wood biofuel farmlands with organic soil, where the organic carbon content of the topsoil (up to 20 cm depth) is at least 12%. Climate goal: reduce GHG emissions from the soil, ensure CO_2 sequestration in all carbon stores and substitution effect in the energy sector.
Areas suitable for the implementation of the measure	All farmlands with organic soil are suitable for the implementation of the measure. Before afforestation, it may be necessary to replace closed drainage systems with a network of ditches, as well as to restore existing drainage systems.
Areas not suitable for the implementation of the measure	Afforestation may be restricted by conditions in local government planning documents, as well as restrictions related to meeting nature conservation requirements.
Implementation technology	Before the implementation of the measure, the condition of the drainage systems must be assessed and, if necessary, the existing network of ditches and culverts must be restored, as well as the closed drainage systems must be rebuilt by installing a network of ditches instead. Soil preparation in organic soils is best done with an excavator, creating mounds and planting 1,500-2,000 seedlings per unit area. The most suitable tree species for organic soils are spruce and birch. After planting, tending is required (at least 3 times), but after the trees reach a height of 6-9 m, a maintenance felling of young trees, during which you can already earn the first income by selling wood biofuel, 1-2 maintenance fells and the main felling. Plant protection measures may be necessary in young trees to protect trees from animal damage. The use of wood ash after maintenance felling allows to increase the growth and shorten the cycle time. Duration of circulation 40-60 years.
Restrictions on the implementation of the measure	There are no restrictions on the implementation of the measure, except for the restrictions set in nature protection requirements and territorial plans of local municipalities.

The potential negative effects of the measure on the climate	The measure only has a positive effect on the climate.
Duration of the effect of the measure and actions to maintain the effect	The measure has a long-term impact determined by the original land use, the state of the drainage system, the dominant tree species, the duration of the cycle and the use of wood. In the second and subsequent cycles, the positive impact decreases, but remains significantly greater than other measures, due to the reduction of GHG emissions from the soil.
Effect of the measure on CO_2 removals and GHG emissions	The net reduction potential of greenhouse gases for a 60-year life cycle is around 900 tons of CO_2 eq ha^{-1} (15 tons of CO_2 ha^{-1} per year). In general, during one cycle, this measure can provide at least 150 mill. tons of CO_2 eq reduction of GHG emissions.
Effect of the measure on sustainability aspects	Afforestation of organic soils ensures the restoration of a natural forest ecosystem in previously deforested areas, making a significant contribution to the implementation of the goals of increasing natural diversity.
Cost of implementing of the measure	The cost of afforestation in the first five years at existing prices is 1550 € ha^{-1}. Costs for one circulation cycle (60 years) at current prices are around 13.5 k€ ha^{-1}, including logging, but revenues – 33.5 k€ ha^{-1}. Main cost items: soil preparation, purchase and planting of seedlings, tending and maintenance of drainage systems. Additional costs may be the restoration or reconstruction of drainage systems.
Income from the implementation of the measure	The net income in one circulation cycle, when selling additionally obtained timber and wood biofuel, at current prices is around 20.2 k€ ha^{-1}.
Cost of CO_2 removals and GHG mitigation	The cost of GHG removals over 75 years at current prices is -27.9 € ton^{-1} CO_2 eq at a current prices, but over the life cycle it is -40.0 € ton^{-1} CO_2 eq, excluding substitution effect of biofuel, i.e. the revenue exceeds the cost of the measure. Figure 1 shows the discounted costs of GHG abatement over the life cycle.

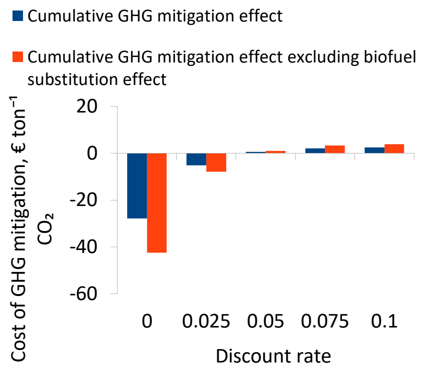


Figure 1. Discounted cost of GHG mitigation

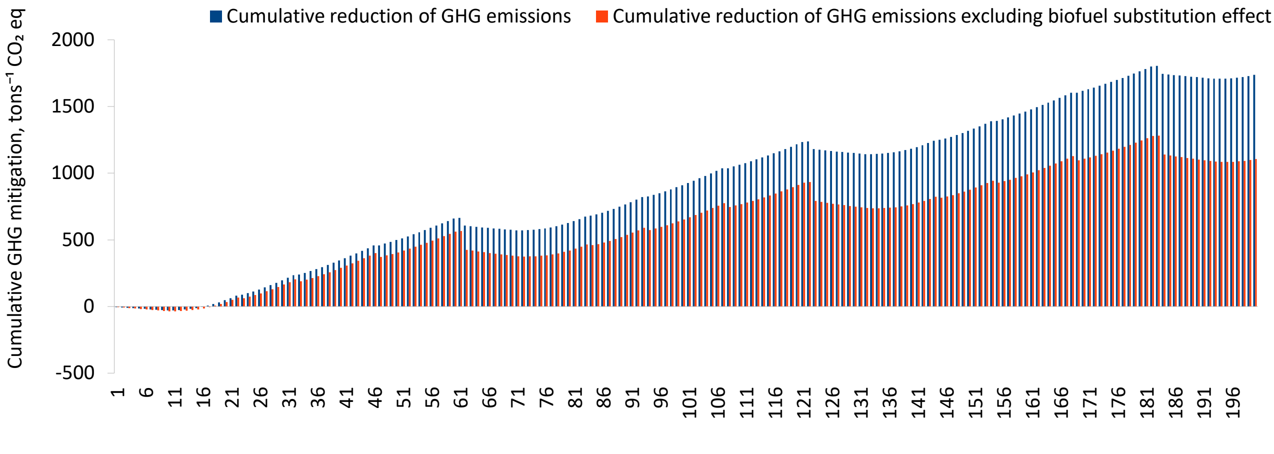


Figure 2. Cumulative climate change mitigation effect of afforestation of organic soils.

2.1.2 Paludiculture – afforestation of grassland with black alder and birch

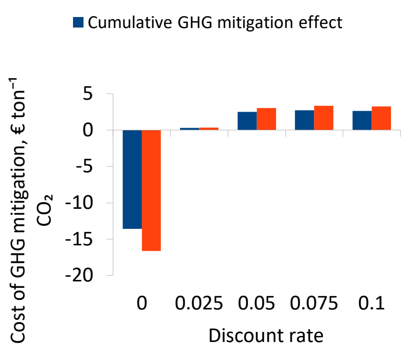
Afforestation of organic soil with following rewetting in grassland and cropland is one of forest restoration methods, applicable in areas with potentially high groundwater level. The scope of this measure is to ensure establishment of forest stand and to contribute to implementation of the biodiversity targets, while keeping positive climate change mitigation balance. The description of this measure is provided in Table 2. The mitigation rate is calculated assuming that grassland is planted with black alder and drainage system is maintained until closure of tree crowns. Duration of rotation – 70 years. Shortening of rotation may increase the net removals, if the output of HWP is increased and regeneration period, when the forest stand is net source of emissions, is not increased. Additional effect can be accessed in case of afforestation of cropland and use of wood ash as a fertilizer. Continuous mitigation effect through several rotations can be accessed through use of selected planting material ensuring increase of growing stock by 10-20% every next rotation and by increase the resilience of forest stands.

Cumulative effect of the measure is shown in Figure 4. The net mitigation effect in long term is similar to the afforestation; however, it is associated with higher risk of natural disturbances, mainly due to periodic flooding during vegetation season, and secondary disturbances in weakened stands. The assumptions used in calculations are based on recent research results and IPCC guidelines (Butlers et al., 2023; Butlers, Lazdiņš, et al., 2022; Butlers, Spalva, et al., 2022; Hiraishi et al., 2013).

Table 2. Afforestation and rewetting of organic soils

Objectives of the measure	Economic objective: to produce timber and wood biofuel farmlands with organic soil, where the organic carbon content in the topsoil (up to 20 cm depth) is at least 12% and where restoration or maintenance of drainage systems is not possible. Climate goal: to ensure CO2 sequestration in woody plant biomass, dead wood and wood products in storage and substitution effect in the energy sector.
Areas suitable for the implementation of the measure	Farmlands with organic soil is suitable for the implementation of the measure, where targeted forest management is not possible, maintaining an optimal moisture regime, as well as in areas where nature restoration measures are planned. Also in this measure, it may be necessary to replace closed drainage systems with a network of ditches, as well as to restore the existing

	drainage systems in order to help drain away excess water at a young age, while the tree stand is not yet able to regulate the groundwater level. After that, the drainage systems may not be restored or the groundwater level may be gradually raised, allowing the tree stand to adapt to the new conditions.
Areas not suitable for the implementation of the measure	Afforestation may be restricted by conditions in local government planning documents, as well as restrictions related to meeting nature conservation requirements.
Implementation technology	Before the implementation of the measure, the condition of the drainage systems must be assessed and, if necessary, the existing network of ditches and culverts must be restored, as well as the closed drainage systems must be rebuilt by installing a network of ditches instead. Soil preparation in organic soils is best done with an excavator, creating mounds and planting 1,500-2,000 seedlings per unit area. When preparing the soil, it is necessary to install deep furrows in order to prevent water from accumulating in the relief depressions or to drain water to the deeper relief depressions. When closing drainage systems, the situation that old ditches lead water to the afforested area should be prevented. The most suitable tree species for organic soils are black alder and birch. Pine is recommended to be planted in the less fertile transition bog peat soils. After planting, tending is required (at least 3 times), but after the trees reach a height of 6-9 m, young growth pruning, 1-2 stock maintenance pruning and the main pruning with the method of gradual strip or random felling in order to maintain the ability of the tree stand to regulate groundwater level. Plant protection measures may be necessary in young trees to protect trees from animal damage. The use of wood ash after maintenance felling allows to increase the growth and shorten the cycle time, and also helps the stand to regulate the groundwater level more efficiently due to faster tree growth. The life span is 60-80 years, but the life span can also be shortened if the growing conditions are good enough.
Restrictions on the implementation of the measure	There are no restrictions on the implementation of the measure, except for the restrictions set in nature protection requirements and territorial plans of local municipalities, as well as in areas where the closure of drainage systems would significantly worsen the hydrological regime in the surrounding areas.
The potential negative effects of the measure on the climate	The measure may increase methane (CH_4) emissions from the soil, as well as increase the risk of natural disturbances, significantly reducing the expected positive impact or even increasing GHG emissions compared to the current situation.
Duration of the effect of the measure and actions to maintain the effect	The measure has long-term effects determined by the original land use, hydrological regime, dominant tree species, rotation duration and wood use. In the second and subsequent cycles, the positive effect decreases.
Effect of the measure on CO_2 removals and GHG emissions	The net reduction potential of greenhouse gases for a 60-year life cycle is around 350 tons of CO_2 eq. ha-1 (5 tons of CO_2 eq. ha-1 per year). In general, during one cycle, this measure can provide at least 28 million. tons of CO_2 eq. a large reduction in emissions if 50% of organic soils in farmlands are rewetted. The emission reduction is 3.5 times lower than if rewetting were abandoned in these areas.
Effect of the measure on sustainability aspects	Afforestation of organic soils ensures the restoration of a natural forest ecosystem in previously deforested areas, making a significant contribution to the implementation of the goals of increasing natural diversity.
Cost of implementing of the measure	The cost of afforestation in the first five years at current prices is 3.1 thousand. € ha-1. Costs for one circulation cycle (70 years) at current prices are around 8.6 thousand. € ha-1, including logging, but revenues – 18.5 thousand. € ha-1. Main cost items: soil preparation, purchase and planting of seedlings, tending and maintenance of drainage systems. Additional costs may be the restoration, reconstruction and gradual closure of drainage systems.
Income from the implementation of the measure	The net income in one circulation cycle, selling the additionally obtained timber and wood biofuel, at current prices is around 9.9 thousand. € ha-1. The net income can be significantly (2-3 times) reduced by the need to replace clear felling with gradual felling.

Cost of CO_2 removals and GHG mitigation	The cost of GHG removals over 75 years at current prices is -16.6 € ton^{-1} CO_2 eq at a current prices, but over the life cycle it is -24.1 € ton^{-1} CO_2 eq, excluding substitution effect of biofuel, i.e. the revenue exceeds the cost of the measure. Figure 3 shows the discounted costs of GHG abatement over the life cycle.	 **Figure 3. Discounted cost of GHG mitigation**

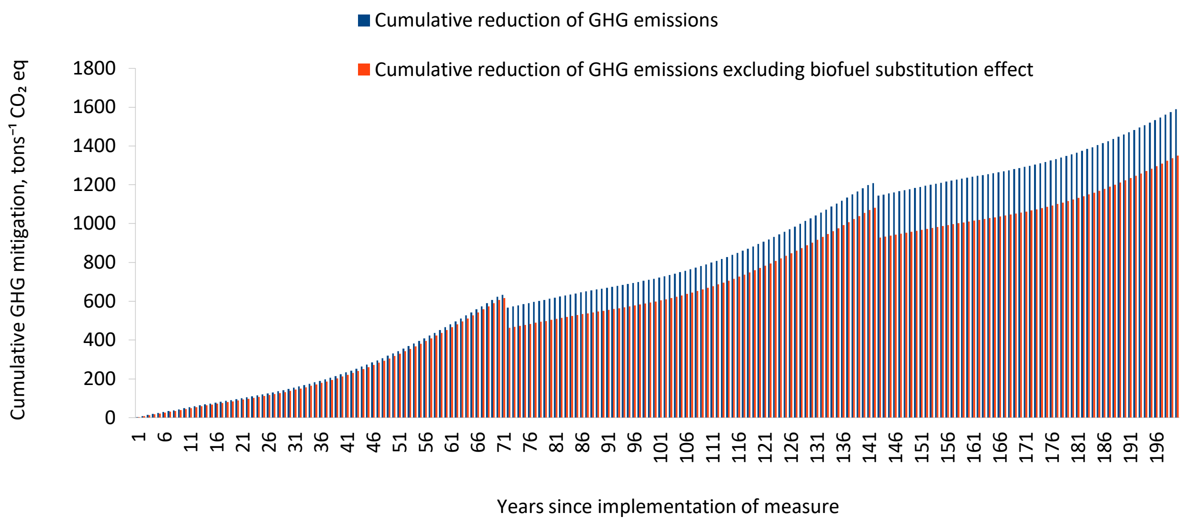


Figure 4. Cumulative climate change mitigation effect of establishment of forested paludicultures.

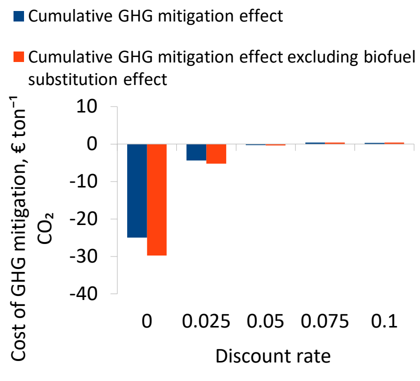
2.1.3 Application of wood ash after commercial thinning in spruce stands

Application of wood ash (5-10 tons ha^{-1}) after commercial thinning (2-3 time per rotation) is one of the most efficient climate change mitigation measures ensuring the effect in short time, directly after application of wood ash. The scope of this measure is to increase carbon stock in living biomass, particularly, in large dimension timber assortments. The description of this measure is provided in Table 3. The mitigation rate is calculated assuming that wood ash is applied after every thinning ensuring cumulative increment effect, and drainage system is well maintained to avoid periodic flooding during vegetation season. Duration of rotation – 60 years, assuming that regenerative felling is planned after reaching the target diameter. Shortening of rotation may increase the net removals, if the output of HWP is increased and regeneration period, when a forest stand is net source of emissions, is not increased. Continuous mitigation effect through several rotations can be accessed through use of selected planting material ensuring increase of growing stock by 10-20% every next rotation and by increase the resilience of forest stands.

Cumulative effect of the measure is shown in Figure 6. The assumptions used in calculations are based on recent research results (Ahtikoski & Hökkä, 2019; Bārdule et al., 2021; Hökkä et al., 2012; Huotari et al., 2015; Petaja et al., 2018, 2021).

Table 3. Application of wood as in forestry after thinning

Objectives of the measure	Economic objective: to promote additional growth of wood, which increases the yield of round timber and forest biofuel. Climate goal: increase CO_2 sequestration in forest lands, promoting additional wood growth and carbon accumulation in all storages.
Areas suitable for the implementation of the measure	Fir, pine and birch stands of grade II-V with improved organic soils (peats) are suitable for fertilizer application, where economic activity is permitted, and other environmental conditions, such as periodic flooding, do not limit the growth of trees. Even in forest stands of higher ratings, growing conditions may deteriorate periodically, because organic soils have several times smaller reserves of phosphorus and potassium than in mineral soils, and nutrient reserves may run out in fast-growing stands. The economic goals can be fully implemented in II-III quality stands, where the main felling with the clear-cutting method is allowed.
Areas not suitable for the implementation of the measure	The use of wood ash is not useful in forest stands with over-moistened peat soils (swamps), in areas where maintenance felling has not been carried out. In mineral soils, wood ash can be replaced with phosphorus and potassium mineral fertilizers. Wood ash can be more effective in lower site index (III-IV) plantations if it is spread together with nitrogen fertilizers. The cross-sectional area of the trees to be preserved in maintenance felling should be close to the minimum in order to ensure a sufficiently large growth space, otherwise the effect of wood ash will not be manifested and additional growth will not be formed, although the spreading of wood ash also in such stands will reduce the risk of natural disturbances, improving the vitality of the trees.
Implementation technology	Before spreading, the ash must be treated by mixing it with water and allowing it to react with the CO_2 in the air. The treatment process takes a few months. As a result of processing, hydroxides are formed from potassium, calcium and magnesium oxides, and then carbonates, which are less active, do not cause plant burns and are more slowly leached from the soil. As a result of processing, the ash hardens into a poor quality concrete-like mass, so the ash can be processed into pellets, press-formed "sausages" or simply crushed into a gravel-like mass that can be easily spread with equipment suitable for spreading mineral fertilizers or road maintenance. Wood ash is spread in forest stands after maintenance felling, using agricultural tractor equipment or forest machinery adapted for fertilizer spreading and driving along the technological corridors cut in the maintenance felling. To ensure even spreading, the fertilizer should be spread in as wide, overlapping bands as possible. Wood ash can be spread throughout the year, however, the best time to spread ash is winter, when the soil is frozen, or summer, if the soil's bearing capacity is sufficient. The dosage of wood ash is 3-5 tons ha-1, but the dosage can be increased to 10 tons to increase the duration of the effect. The need to apply ash is evaluated by analysing the leaves and needles of trees cut in maintenance felling and comparing the result, for example, with the recommendations for optimal phosphorus and potassium content developed in Finland. In Latvia, such tables of nutrient supply limit values have not yet been developed. Fertilizer can be used several times in the circulation cycle, every 7-10 years or after each care cutting. Wood ash should be applied in such a way as not to increase damage to trees, including roots. By carrying out maintenance felling more often and shortening the cycle (up to 40-60 years), wood ash, like mineral fertilizer, can at least double the absorption of CO2 in forests within 200 years.
Restrictions on the implementation of the measure	The use of wood ash is not recommended in areas with restrictions on economic activity, as well as in forest stands where economically less valuable tree species grow, because in such areas it will not be possible to fully implement the economic goals of using wood ash. In forest stands with fertile soils, as well as in thickened stands, the effect of fertilization may not be manifested, because in such stands the availability of nutrients does not limit the growth of trees or the trees lack the growth space to form additional growth. However, even in such areas, the spreading of wood ash reduces the risk of natural disturbances.
The potential negative effects of the measure on the climate	As a result of the implementation of the measure, fuel consumption in forest operations may increase, but the ratio between the fuel consumed and the wood obtained improves, i.e. GHG emissions per unit of CO_2 generated by the equipment decrease.

Duration of the effect of the measure and actions to maintain the effect	The effect lasts at least 5-10 years after the spreading of the ash, but in lower quality stands it persists throughout the cycle. In order to ensure a long-term effect, the application of wood ash should be repeated, as well as maintenance felling should be performed in a timely manner (more often than in routine forestry). In forest management, good practice guidelines must be followed, timely and sufficiently intensive maintenance felling and maintenance of drainage systems in good technical condition. Economically less valuable tree species should be replaced by more valuable tree species suitable for specific conditions.
Effect of the measure on CO_2 removals and GHG emissions	Additional growth as a result of forest soil improvement can provide 13 million tons of CO2 during two forest management cycles, if only the short-term effects are evaluated, without taking into account the effect of shortening the life cycle. The effect of one application of fertilizer corresponds to approximately 20 tons of CO_2 ha^{-1}, respectively, during the management cycle this effect can reach 60 tons of CO_2 ha^{-1}. An additional effect is caused by the reduction of CH_4 and N_2O emissions from the soil, but methods for evaluating this effect have not yet been developed in Latvia.
Effect of the measure on sustainability aspects	Remediation of poor soils can lead to changes in understory vegetation with the introduction of species characteristic of more fertile growing conditions. Ash spreading promotes microbiological activity in the soil, which can lead to a temporary increase in CO2 emissions from the soil.
Cost of implementing of the measure	The cost of ash spreading in 2022 prices is 120 € ha-1. In Finland, forest owners pay up to €300 ha-1 for ash spreading, including wood ash delivery, processing and payment for wood ash to ash producers. In Finland, the situation is different than in Latvia, because there the demand for wood ash exceeds the supply. In Latvia, wood ash is still illiquid or even hazardous waste, and the use of ash in the forest allows reducing the costs of ash management compared to depositing it in landfills. Costs per cycle (60 years) at current prices are around €400 ha^{-1}, but up to €1000 ha^{-1} in Finland. In Baltic states this practice is not implemented yet and real costs are not known. It is important that national subsidies can significantly affect cost of this measure. Main cost items: loading and spreading. Additional costs are analyses of the chemical composition of needles and leaves, around 50 € per cut.
Income from the implementation of the measure	The additional net income in one circulation cycle, from the sale of additionally obtained timber and wood biofuel, at current prices is around 3.7 thousand. € ha^{-1}.
Cost of CO_2 removals and GHG mitigation	The cost of GHG removals over 75 years at current prices is -29.76 € ton^{-1} CO_2 eq at a current prices, but over the life cycle it is – 31.2 € ton^{-1} CO_2 eq, excluding substitution effect of biofuel, i.e. the revenue exceeds the cost of the measure. Figure 5 shows the discounted costs of GHG abatement over the life cycle.  **Figure 5. Discounted cost of GHG mitigation**

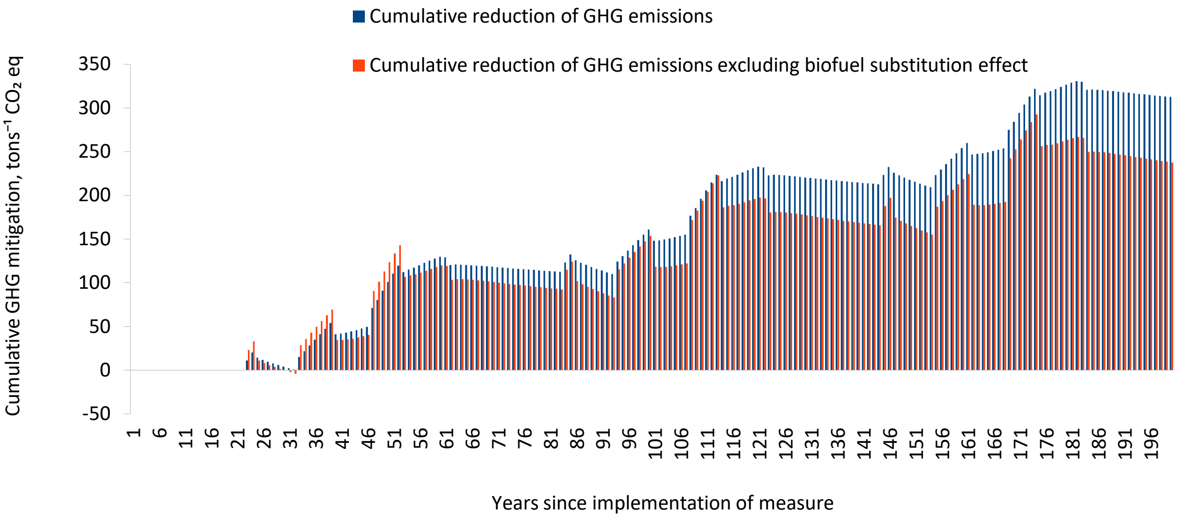


Figure 6. Cumulative climate change mitigation effect of application of wood ash to improve forest growth.

2.2 Climate change mitigation actions in agriculture land

Paquel et al. (2017) concluded that the main option to reduce GHG emissions from organic soils in Netherlands is to elevate the groundwater level in order to reduce the oxidation of the organic material. This can be done either by technical measures or through increasing the water level and extensification of the land use. One of the technical options is the use of submerged drainage, which still allows for agricultural activities, but reduces emissions. A first analysis for the Netherlands shows that the use of submerged drains and raising water levels for grassland areas with deep drainage could reduce emissions from organic soils by 1-2 mill. tons CO_2 per year, which would be a reduction of about 35%. Extrapolating this reduction to all grassland under organic soils in the EU would lead to a potential mitigation of about 13 mill. tons CO_2 per year. In addition N_2O emissions from cultivated organic soils, which are reported under the sector Agriculture, will be reduced as well if measures are taken. These emissions are currently reported at 13 mill. tons CO_2-eq per year (EU NIR 2017) and could be reduced by 4.7 mill. tons CO_2-eq (36%, which is the same reduction percentage as for CO_2). Consequently a total mitigation potential of about 30 mill. tons CO_2-eq yr^{-1} would be possible for organic soils under grassland and cropland (Paquel et al., 2017).

Kekkonen et al. (2019) within the study in Finland reported that for the fields on organic soils potentially removable from cultivation, afforestation is a viable option from a life-cycle analysis viewpoint, but the emissions of N_2O at least will continue at a rate similar to those of cultivated soils, excluding fertilization related emissions. Afforestation involves drainage as well, and as long as there is peat above the groundwater level it will be prone to decomposition. The most efficient mitigation measure in these cases can be rewetting. It runs the risk of high CH_4 emissions and high nutrient losses to watercourses, but in some cases has been found to turn agricultural sites carbon neutral or to carbon sink. With the right crop selection, it may even be possible to continue cultivation in rewetted conditions (i.e. paludiculture).

The conversion of agricultural land into nature or paludiculture (i.e. productive use of wet and rewetted peatlands) is a more effective option, but also has a larger impact and might be more appropriate in areas where land is cheaper and less intensively used. In the EU, for cropland on organic soils a land use conversion to extensive grassland or nature would be the most relevant option, as the cropland area on organic soils is relatively small, only about 1.3% of the total cropland area, whereas emissions from that land are very high. It is assumed that half of this land could be taken out of production or converted to more extensive grassland use. This could result in an emission reduction of about 12 mill. tons CO_2-eq yr^{-1} (assuming emissions are reduced by 75% after conversion). Several EU Member States consider or have already policies for the conversion of arable land on organic soils to nature or grassland, e.g. Denmark, Luxembourg, Latvia, and Germany. However, a quantification of the mitigation potential is mostly not provided. Latvia reported for instance that "conversion of 1 ha of cropland to grassland considering 5.2% share of organic soils [in Latvia] would reduce CO_2 emissions by 0.3 tonnes CO_2 ha^{-1} annually" (Paquel et al., 2017). As noted before there is no scientific approval for this assumption.

Combination of rewetting and paludiculture is pursued as a wider CO_2 mitigation option in drained organic soils. Paludiculture combines biomass production at higher water levels by using both lightweight harvesting machines and flood tolerant crop species (e.g. *Typha*, *Azolla*, *Sphagnum*, *Phragmites*, *Salix* and *Alnus*). However, information on the overall GHG balance for paludiculture is lacking. Karki et al. (2014) investigated the GHG balance of peatlands grown with reed canary grass (RCG) and rewetted to various extents. Raising the GWL to the surface decreased both the net ecosystem exchange (NEE) of CO_2 and N_2O emissions whereas CH_4 emissions increased. Total cumulative GHG emissions (for 10 months) corresponded to 0.08, 0.13, 0.61, 0.68 and 0.98 kg CO_2 eq. m^{-2} from the GWL treatments at 0, -10, -20, -30 and -40 cm below the soil surface, respectively. The results showed that a reduction in total GHG emissions can be achieved without losing the productivity of newly established RCG when GWL is maintained close to the surface (Karki et al., 2014).

In Sweden, Norberg (2017) evaluated GHG emissions from cultivated organic soils including effect of cropping system, soil type and drainage. The overall conclusion was that no specific crop can be considered as a way to mitigate climate change by reducing greenhouse gas emissions from drained cultivated peat and carbon-rich soils during the growing season. Site-specific effects were a key factor for the greenhouse gas emissions rather than the cropping system. Furthermore, there was no difference in carbon dioxide emissions between a groundwater level at 50, 75 and 100 cm below the soil surface. Only carbon dioxide emissions at near water-saturated conditions deviated significantly. In most peat soils, maximum carbon dioxide emissions occurred already at low soil water suction (0.5 m water column).

For instance, in Finland, instead of intensive food or feed production, some cultivated peatlands are in extensive use due to poor productivity or challenging cultivation conditions. Such low-yielding, thick layered peat soils in extensive use would be more useful to either be rewetted, restored or under paludiculture in order to meet the emission targets. Such plots can be found in Finland about 23,000 ha, which is approximately 1% of the total cultivated area (Kekkonen et al., 2019). By rewetting, restoring or transferring these fields to paludiculture, Finland could reduce about 10% of the emissions from cropland in the land use and land use change sector. In general, paludicultures are considered as natural ecosystems. In the long term, mire vegetation captures carbon and "stores" it in peat.

In agricultural land including organic soils, agroforestry provides for greater C sequestration than through conventional options alone while leaving the bulk of the land in agricultural production. In large parts of temperate and boreal Europe, implementation of afro-forestry remains rather limited. Besides uncertainties on the legislative and economic level, this might result from a lack of actual quantification of the ES provided and the lack of knowledge on implications of agroforestry on field management. Under temperate and boreal climatic conditions actual quantitative estimates of climate mitigation impact especially in lands on organic soils remain extremely scarce. Thus, further research and quantification is needed regarding the effect of tree presence on soil organic carbon and net GHG emissions in organic soils (Pardon et al., 2017; Schoeneberger et al., 2012).

A key component for sustaining production in grassland ecosystems is the maintenance of soil organic matter (SOM), which can be strongly influenced by management. Many management techniques intended to increase forage production may potentially increase SOM, thus sequestering atmospheric carbon. (Conant et al., 2001) reviewed studies examining the influence of improved grassland management practices and conversion into grasslands on soil C worldwide to assess the potential for C sequestration. Results from 115 studies containing over 300 data points were analysed. Management improvements included fertilization (39%), improved grazing management (24%), conversion from cultivation (15%) and native vegetation (15%), sowing of legumes (4%) and grasses (2%), earthworm introduction (1%) and irrigation (1%). Soil C content and concentration increased with improved management in 74% of the studies, and mean soil C increased with all types of improvement. Carbon sequestration rates were highest during the first 40 years after treatments began and tended to be greatest in the top 10 cm of soil. Impacts were greater in woodland and grassland biomes than in forest, desert, rain forest, or shrubland biomes. Conversion from cultivation, the introduction of earthworms, and irrigation resulted in the largest increases. Rates of C sequestration by type of improvement ranged from 0.11 to 3.04 Mg C ha^{-1} yr^{-1}, with a mean of 0.54 Mg C ha^{-1} yr^{-1} and were highly influenced by biome type and climate. Conant et al. (2001) concluded that grasslands can act as a significant carbon sink with the implementation of improved management. Also Conant et al. (2017) concluded that improved grazing management, fertilization, sowing legumes and improved grass species, irrigation, and conversion from cultivation all tend to lead to increased soil C, at rates ranging from 0.105 to more than 1 Mg C ha−1 yr−1. These are general assumptions that apply mainly to SOM in mineral soils. Further studies are necessary to specify impacts of different management approaches in grasslands on organic soils on net GHG emissions at ecosystem level in boreal and temperate cool moist climate zone at ecosystem level.

Within the study in the Republic of Ireland Renou-Wilson et al. (2012, 2016) concluded that extensive grassland over organic soil is on average, an annual source of CO_2 when drained (138-232 g C m^{-2} yr^{-1}) and a sink when rewetted (-40 g C m^{-2} yr^{-1} in the ungrazed rewetted grassland). A wet organic soils under grassland display high CH_4 emissions especially if the water is close to the surface. However, maintaining the water table at – 20 cm may be sufficient to reduce CO_2 losses from respiration while keeping CH_4 emissions low and therefore raising the water table could be used as a GHG mitigation tool in organic soils under grassland.

In Finland, as forage production as rotational grasses is classified as cropland in the GHG inventory, Finnish grasslands are mainly abandoned fields and thus there are limited possibilities to guide their management. Some abandoned fields have been successfully rewetted and restored to close to natural state.

In Latvia scientists observed that grasslands remains significant source of GHG emissions even if peat layer is less than 10 cm, which means that the emissions from grasslands, as well as the mitigation potential is underestimated (Purvina et al., 2023; Purviņa et al., 2024). It was also found that rewetting may not be associated with decrease of GHG emissions; however, these findings applies to nutrient-poor soils (Bārdule et al., 2023) and further studies are necessary in nutrient-rich soils.

2.2.1 Agroforestry – fast growing trees and grasses in arable land with organic soils

Growing of fast growing trees and farm crops, e.g., grasses for seed or fodder production in cropland and grassland with organic soil is the most efficient climate change mitigation measure from the studied methods. Growing of fast growing trees in arable land with organic soil is also the measure with the biggest implementation potential; however, it is also associated with significant risks of natural disturbances. In our trials planted trees suffered from draught and animal damages, highlighting that fencing is mandatory action to succeed with this measure. It seems that drought is important risk in organic soils, and it can be avoided by proper soil preparation, use of appropriate planting material (thick long-cuttings), deep planting and careful weed control during the first years after planting. Assuming that plantation survives and is not significantly damaged by draught or animals the net emission reduction in the 75 years period will reach 1560 tons CO_2 eq ha^{-1}, 20 tons CO_2 eq ha^{-1} yr^{-1} (Table 4). Bioenergy production will contribute to additional substitution effect – 784 tons CO_2 eq ha^{-1} yr^{-1}. It is assumed that the trees are primarily used for timber and pulp production. In case of bioenergy targeted plantation the most of the effect will appear as a substitution effect in energy sector. The positive effect can be increased further by periodic application of wood ash and mineral fertilizers. These measures can be considered as mandatory in the most cases to ensure high growth rates. In this report is is assumed that the area is planted with hybrid poplar and drainage system is well maintained to avoid periodic flooding of the plantation. Selection of other species, e.g. hybrid aspen or alder, may result in different mitigation effect.

Cumulative effect of the measure is shown in Figure 8. The effect of the measure is based on several studies implemented in Latvia and IPCC guidelines (Bardule et al., 2016; Daugaviete et al., 2020, 2022; Hiraishi et al., 2013; Lazdiņa et al., 2019).

Table 4. Fast growing trees and grasses in arable land with organic soils

Objectives of the measure	Economic goal: to produce timber and wood biofuel in less valuable farmlands. Climate goal: ensure CO_2 sequestration in all carbon stores and substitution effect in the energy sector.
Areas suitable for the implementation of the measure	All farmlands with mineral soils are suitable for the implementation of the measure. Currently, receiving state aid is limited by the threshold value of the land value - 30 points. It may be necessary to replace the closed drainage systems with a network of ditches, as well as the restoration of the existing drainage systems, before planting trees.
Areas not suitable for the implementation of the measure	The implementation of the measure may be limited by conditions in the planning documents of the local municipality, as well as restrictions related to the fulfilment of nature protection requirements. It is not useful to implement the measure in small areas (less than 1 ha) in order to reduce the costs

	of moving machinery, as well as in areas that are not accessible by agricultural machinery. Poplar and aspen hybrid plantations are not recommended to be planted next to pine saplings.
Implementation technology	Before the implementation of the measure, the condition of the drainage systems must be assessed and, if necessary, the existing network of ditches and culverts must be restored, as well as the closed drainage systems must be rebuilt by installing a network of ditches instead. Soil preparation is best done with an excavator, creating mounds or turning the sod and planting 1000-1500 seedlings per unit area. Fast-growing aspen and poplar hybrids, whose winter hardiness and disease resistance have been tested in Latvia, are suitable for tree plantations. Before planting, prepare the soil (continuous ploughing and cultivation). It is recommended to leave green fallow in the area before establishing a tree plantation to reduce the amount of weeds. Planting in spring – aspen hybrid frame seedlings are planted with planting barrels or mechanized with specialized planting machines (suitable for small-sized seedlings), while poplar hybrids are planted mechanized as 1.5-2 m long cuttings. To ensure good rooting of the cuttings, the soil must be prepared in the same way as before sowing cereals. Three to four years after planting, tending by destroying competing weeds and plant protection measures using means that repel large ungulates are required. An alternative solution is the construction of a temporary or permanent fence around the plantation of woody plants, so it is essential that the area of continuous plantation of woody plants is as large as possible and of regular shape. After the trees reach a height of 6-9 m in denser plantations, young maintenance pruning may be necessary, removing damaged or competing trees. Usually, the thickness of the planting is such that maintenance pruning is not necessary. The main felling is done 20-25 years after planting with the clear-cutting technique. After the main felling, the area is cultivated as an offshoot by cutting the excess trees in the maintenance of young trees. It is recommended to replant the plantation from seedlings no more than 2 times, taking into account the fact that the proportion of less valuable types of timber and firewood will increase significantly in the last cycle. After the last rotation, the area should be recultivated by pulling out stumps, tilling the soil and planting new, more disease-resistant and faster-growing clones of woody plants. Stumps can be used as fuel. The use of mineral fertilizers (NP) (once in 5-7 years after the crowns of the trees collapse) can increase the growth, but no scientific evidence of the effectiveness of fertilizers has been obtained yet. In order to be able to cut trees after reaching the target diameter, the tree plantation must be registered as a plantation forest. The maximum 15-year rotation period for tree plantations established by Latvian regulations is not economically justified, so the choice of such land use type is recommended only if it is planned to grow wood biofuel on the area.
Restrictions on the implementation of the measure	The implementation of the measure may be limited by nature protection requirements and the requirements for land use set in the territorial plans of local municipalities.
The potential negative effects of the measure on the climate	The measure only has a positive effect on the climate, but in the first decade after the establishment of the tree plantation, as the soil structure improves, the loss of carbon from the soil increases and the accumulation of soil carbon in the soil temporarily decreases.
Duration of the effect of the measure and actions to maintain the effect	The measure has a long-term effect, which is determined by the original land use, the condition of the drainage system, the tree species, the duration of the cycle and the use of the wood. In the second and subsequent cycles, the positive effect decreases, because in parallel with CO_2 sequestration in tree biomass, CO_2 is released from dead wood, wood products and other carbon stores.
Effect of the measure on CO_2 removals and GHG emissions	The net greenhouse gas reduction potential for a 60-year life cycle is around 1610 tons CO_2 ha^{-1} (27 tons CO_2 ha^{-1} per year), excluding the substitution effect, and 2130 tons CO_2 ha^{-1} if the calculation includes the substitution effect of wood biofuel There has been no evaluation of the potential of establishing tree plantations, but 10 thousand. ha, till the end of century (75 years), this measure can provide about 15 million tons of CO_2, a large reduction in emissions, if the substitution effect is not taken into account, and 23 million tons of CO_2, a large reduction in emissions if the calculation includes the substitution effect of wood biofuel.
Effect of the measure on sustainability aspects	One of the most frequently mentioned problematic aspects related to the impact of woody plant plantations on natural diversity is the use of genetically homogeneous material in large areas, which increases the risk of natural disturbance, therefore several clones should be used in woody plant plantations, the continuous improvement of industrial clones and the renewal of plantations using new and more resistant clones of woody plants should be ensured. . The establishment of tree plantations will contribute to the

	achievement of long-term climate neutrality goals in the energy sector, significantly increasing the supply of forest biofuel in the long term.
Cost of implementing of the measure	The cost of planting tree plantations in the first five years at current prices is around 2450 € ha^{-1}. Costs for one circulation cycle (60 years) at current prices are around 28.5 thousand. € ha-1, including logging, but revenues – 62.3 thousand. € ha^{-1}. Main cost items: soil preparation, purchase and planting of seedlings and tending. Additional costs may be the restoration or rebuilding and maintenance of drainage systems, as well as plant protection measures and fence construction.
Income from the implementation of the measure	The net income in one circulation cycle, selling timber and wood biofuel, at current prices, is around 33.9 thousand. € ha^{-1}.
Cost of CO_2 removals and GHG mitigation	The cost of GHG removals over 75 years at current prices is -11.0 € ton^{-1} CO_2 eq at a current prices, but over the life cycle (around 60 years) it is -7.5 € ton^{-1} CO_2 eq, excluding substitution effect of biofuel, i.e. the revenue exceeds the cost of the measure. Figure 7 shows the discounted costs of GHG abatement over 75 years period.

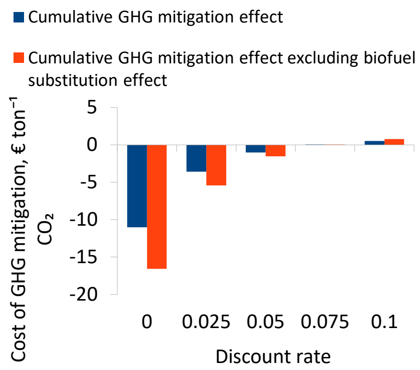


Figure 7. Discounted cost of GHG mitigation

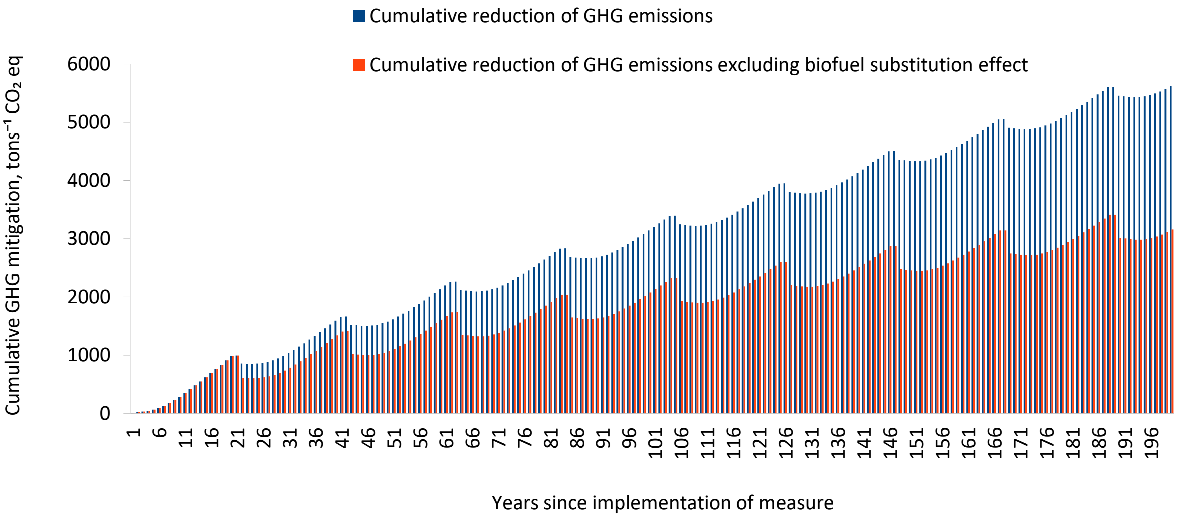


Figure 8. Cumulative climate change mitigation effect of fast growing tree species in arable lands.

2.2.2 Conversion of cropland used for cereal production into grassland

Transformation of arable lands with organic soil into grasslands is one of the most common measures in real life conditions, since farmers are using it to implement greening measures in agriculture and to retain subsidies and support payments dedicated for farmlands and not available for the forest lands. In spite the results acquired during the study demonstrates either increase or reduction of the emissions due to implementation of this measure. In optimistic scenario net emission reduction in the 75 years period will reach 205 tons CO_2 eq ha^{-1}, 2.7 tons CO_2 eq ha^{-1} yr^{-1}. The description of the measure is provided in Table 5. Bioenergy production doesn't have effect in this measure. It is assumed that grassland is used for fodder production without additional input of organic fertilizers.

Table 5. Conversion of cropland used for cereal production into grassland

Objectives of the measure	Economic objective: producing hay in areas with organic soils. Climate goal: to ensure the reduction of GHG emissions from the soil and to increase carbon accumulation in ground cover plant biomass.
Areas suitable for the implementation of the measure	Farmland with organic soil are suitable for the implementation of the measure, where afforestation is not possible, for example, areas where local governments do not give permission for land transformation.
Areas not suitable for the implementation of the measure	Biologically valuable grasslands, where restrictions on economic activity prevent the achievement of economic goals.
Implementation technology	Before the implementation of the measure, the state of drainage systems should be assessed and, if necessary, the existing network of ditches and culverts should be restored, as well as closed drainage systems should be restored. In the spring, the area to be transformed is ploughed, cultivated, sown with mineral fertilizer NPK (15:15:15; 150 kg ha-1 in the first year and 300 kg ha^{-1} in the 2^{nd}-5^{th} year), grass seeds are sown, the sowing is done, mowed, weeded and watered the wall. Starting from the 2nd year, only hay preparation is carried out.
Restrictions on the implementation of the measure	There are no restrictions on the implementation of the measure, except for those specified in nature protection requirements and territorial plans of local municipalities. restrictions, as well as in areas where the closure of drainage systems would significantly worsen the hydrological regime in the surrounding areas.
The potential negative effects of the measure on the climate	The measure may increase methane (CH_4) emissions from the soil, as well as increase the risk of natural disturbances, significantly reducing the expected positive impact or even increasing GHG emissions compared to the current situation.
Duration of the effect of the measure and actions to maintain the effect	The measure has long-term effects determined by the original land use, hydrological regime, dominant tree species, rotation duration and wood use. In the second and subsequent cycles, the positive effect decreases.
Effect of the measure on CO_2 removals and GHG emissions	The net reduction potential of greenhouse gases over 75 years is 205 tons of CO_2 eq. ha^{-1} (2.7 tons of CO_2 eq. ha^{-1} per year). In general, within 75 years, this measure can provide at least 4.1 million tons of CO_2 eq. a large reduction in emissions if all arable land with organic soils is transformed into grassland.
Effect of the measure on sustainability aspects	The transformation of organic soils in arable lands into grasslands allows to increase the area of potentially biologically valuable grasslands, making a significant contribution to the implementation of the goals of increasing natural diversity. However, the economic activity (making hay) determines that these areas are mowed in summer and not in autumn as biologically valuable grasslands.
Cost of implementing of the measure	The costs of economic activity in the first five years at current prices are 3.3 thousand. € ha^{-1}. In the calculations, it is assumed that the lawn is reseeded once every 5-7 years. Main cost items: soil preparation, purchase and sowing of seeds, mineral fertilizer, tending and maintenance of drainage systems. Additional costs may be the restoration or reconstruction of drainage systems. Revenues over 5 years are 3.3 thousand € ha^{-1}, so in the conservative scenario, assuming that drainage systems must be renewed and maintained permanently, revenues do not exceed expenses.
Income from the implementation of the measure	The net income of the measure depends on the investments required in the restoration and maintenance of drainage systems, as well as the production intensity (fertilizer use, frequency of sowing and mowing), the price of hay and other factors.

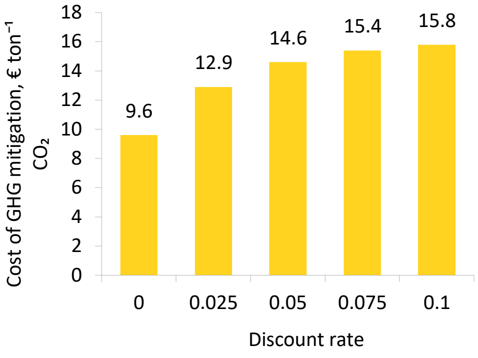
<table>
<tr><td>Objectives of the measure</td><td colspan="2">Economic objective: producing hay in areas with organic soils.
Climate goal: to ensure the reduction of GHG emissions from the soil and to increase carbon accumulation in ground cover plant biomass.</td></tr>
<tr><td>Cost of CO_2 removals and GHG mitigation</td><td>The cost of CO_2 sequestration in 20 years at current prices is around €9.6 per ton of CO_2. The graph shows the discounted costs of GHG abatement over the life cycle (Figure 9).</td><td>

Figure 9. Discounted cost of GHG mitigation</td></tr>
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2.2.3 Fast growing species in riparian buffer zones

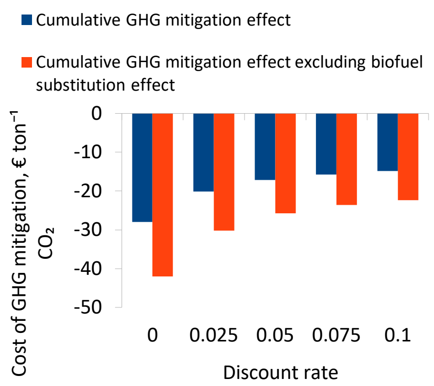
Growing of fast growing trees around drainage ditches in cropland and grassland with organic soil is very efficient climate change mitigation measure; however it can be considered only as supplementary measure for conversion of cropland with organic soil into grassland, assuming that croplands with organic coils are transferred into grassland for fodder production or pastures. Growing of fast growing trees as a shelter belts is very efficient measure with significant implementation potential, but it is also associated with significant implementation risks due to natural disturbances. In our trials plantations suffered from mechanical and animal damages, pointing out that fencing or other plant protection measures are mandatory to succeed with this measure. As mentioned before, drought is significant risk in organic soils, and it can be avoided by proper soil scarification, use appropriate (thick) planting material and deep planting. In optimistic scenario (shelter belt survives and is not significantly damaged by draught or animals) net emission reduction in the 75 years period will reach 1560 tons CO_2 eq ha^{-1}, 20.1 tons CO_2 eq ha^{-1} yr^{-1} (Table 6). Bioenergy production will contribute to additional substitution effect – 784 tons CO_2 eq ha^{-1} yr^{-1}. It is assumed that the shelter belt is primarily used for timber and pulp production. In case of bioenergy targeted plantation the most of the effect will appear as a substitution effect in energy sector. In the calculation is is assumed that the area is planted with hybrid poplar. Selection of other species, e.g. hybrid aspen or alder, may result in different mitigation effect.

Cumulative effect of the measure is shown in Figure 8. The effect of the measure is based on several studies implemented in Latvia and IPCC guidelines (Bardule et al., 2016; Daugaviete et al., 2020, 2022; Hiraishi et al., 2013; Šēnhofa et al., 2019).

Table 6. Growing of shelter belts around drainage systems in farmland

Objectives of the measure	The economic goal: to improve growing conditions in agricultural lands affected by woody vegetation, reduce losses caused by natural disturbances, diversify production in farms and obtain additional income by selling timber and wood biofuel. Climate goal: increase carbon storage in ground cover plant biomass.

Areas suitable for the implementation of the measure	Suitable for the implementation of the measure are agricultural lands (farmlands) that border drainage ditches and where the field area is large enough for the establishment of tree plantations. Tree strips should be placed in the path of the prevailing winds, considering that a strip of 20 m high trees improves the growing conditions in a strip about 60 m wide, accordingly, it is not useful to place strips of trees closer than 60 m from each other.
Areas not suitable for the implementation of the measure	Territories with restrictions on economic activity, where the planting of strips of trees is not allowed, forest edges, where the effect of a strip of trees is provided by a forest wall (in such places, a strip of trees or shrubs contributes to the achievement of environmental protection goals by binding nutrients. The installation of strips of trees is not recommended in places where they can be endangered overhead power lines or the territory has underground infrastructure, including drainage channels. In places where the strip of trees crosses the drainage channel, a ditch (extension) can be dug or drainage pipes can be used, which cannot be overgrown with tree roots.
Implementation technology	Before the implementation of the measure, a project for the placement of tree strips is developed, additional bushes (lower trees) strips are planned on the windward side, as well as along ditches where periodic maintenance is required, openings for entering the fields are planned and the soil is prepared for planting trees. 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. Also in the tree line, it is desirable to plant species that regenerate mainly by stem shoots (poplar, birch). After planting, tending 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 tending. 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	The implementation of the measure may be limited by the requirements of nature protection and maintenance of agricultural lands, as well as technical restrictions on the limitation of tree vegetation strips. The establishment of tree strips does not involve a change in land use.
The potential 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 the 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 effect of the measure and actions to maintain the effect	The measure has a long-term impact, determined by the original land use, the species of trees and shrubs used in the plantation, the duration of the cycle and the use of wood.
Effect of the measure on CO_2 removals and GHG emissions	The net reduction potential of greenhouse gases by planting fast-growing poplar hybrids is around 1610 tons of CO_2 ha^{-1} (27 tons of CO_2 ha^{-1} per year) for a 60-year life cycle. In total, within 30 years, this measure can provide 19 million. tons of CO_2 eq. a large reduction in emissions if 12,000 ha of tree plantations are established.
Effect of the measure on sustainability aspects	Tree plantations 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 that flow to drainage ditches. Tree plantations can also become an important source of wood biofuel and timber.
Cost of implementing of the measure	The cost of setting up tree plantations in the first five years at current prices is 2.5 thousand. € ha^{-1}. The cost per cycle (20 years) at current prices is around 9.5 thousand. € ha^{-1}, including logging, but revenues – 20.8 thousand. € ha^{-1}. Main cost items: soil preparation, purchase and planting of seedlings, tending and logging.

Income from the implementation of the measure	The net income in one circulation cycle, selling additionally obtained timber and wood biofuel, at current prices is around 11.3 thousand. € ha^{-1}.	
Cost of CO_2 removals and GHG mitigation	The cost of GHG removals over 75 years at current prices is -28 € ton^{-1} CO_2 eq at a current prices, but over the life cycle (around 60 years) it is -26 € ton^{-1} CO_2 eq, excluding substitution effect of biofuel, i.e. the revenue exceeds the cost of the measure. Figure 10 shows the discounted costs of GHG abatement over 75 years period.	 **Figure 10. Discounted cost of GHG mitigation**

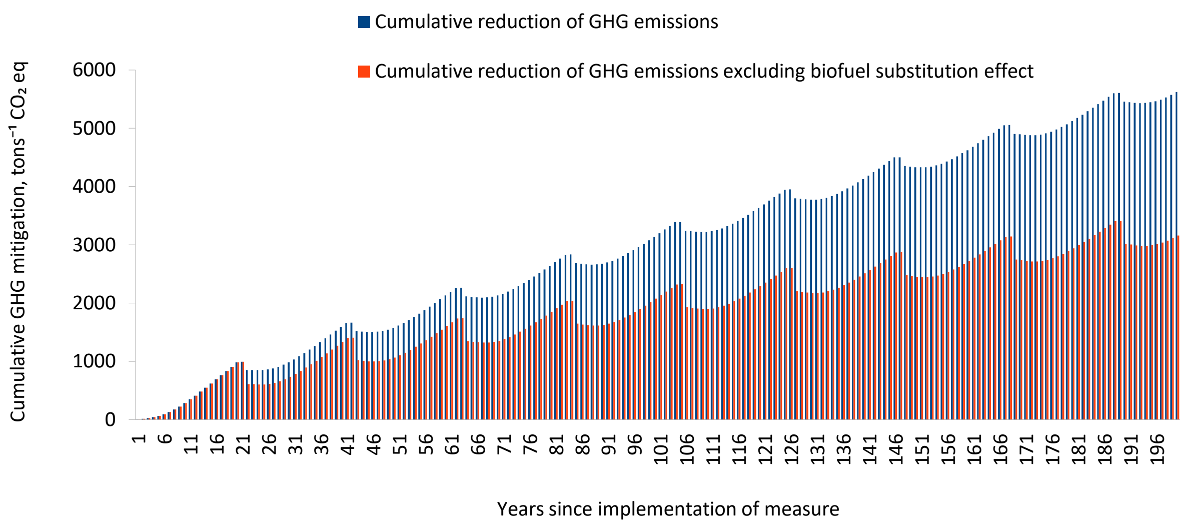


Figure 11. Cumulative climate change mitigation effect of fast growing tree species in shelter belts.

The mitigation effect is calculated for shelter belts consisting of trees (Figure 12). Combined shelter belts consisting of trees and bushes (Figure 13) would contribute less to the climate targets in LULUCF sector, but would have significantly bigger mitigation effect in energy sector due to bigger amount of produced biofuel.

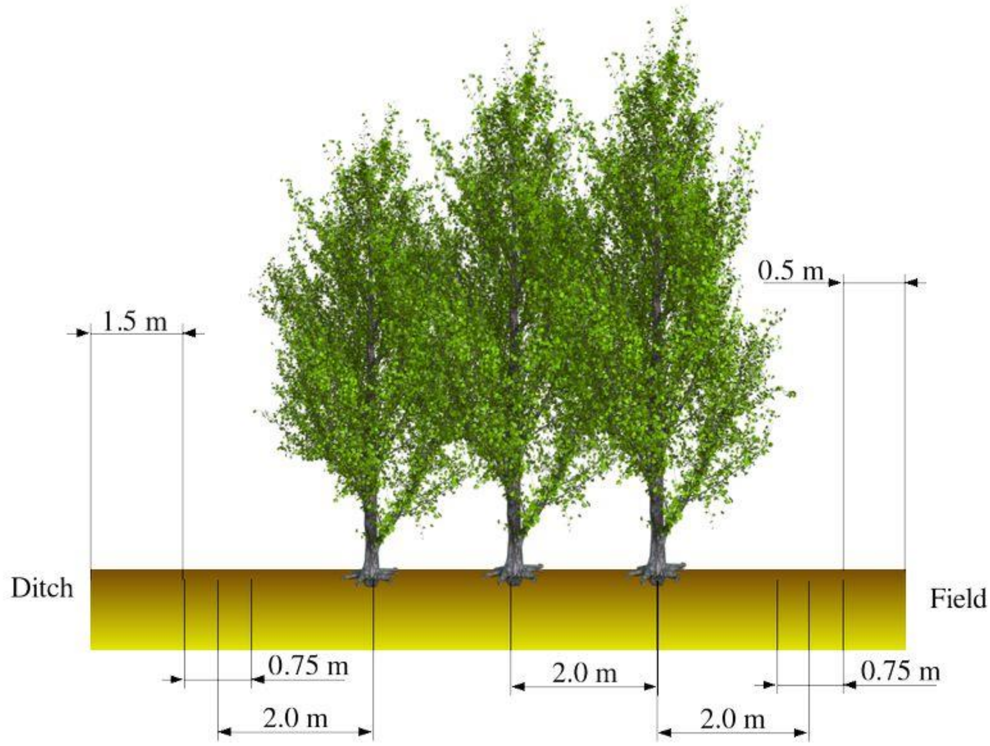


Figure 12. Example of buffer zone consisting of trees only.

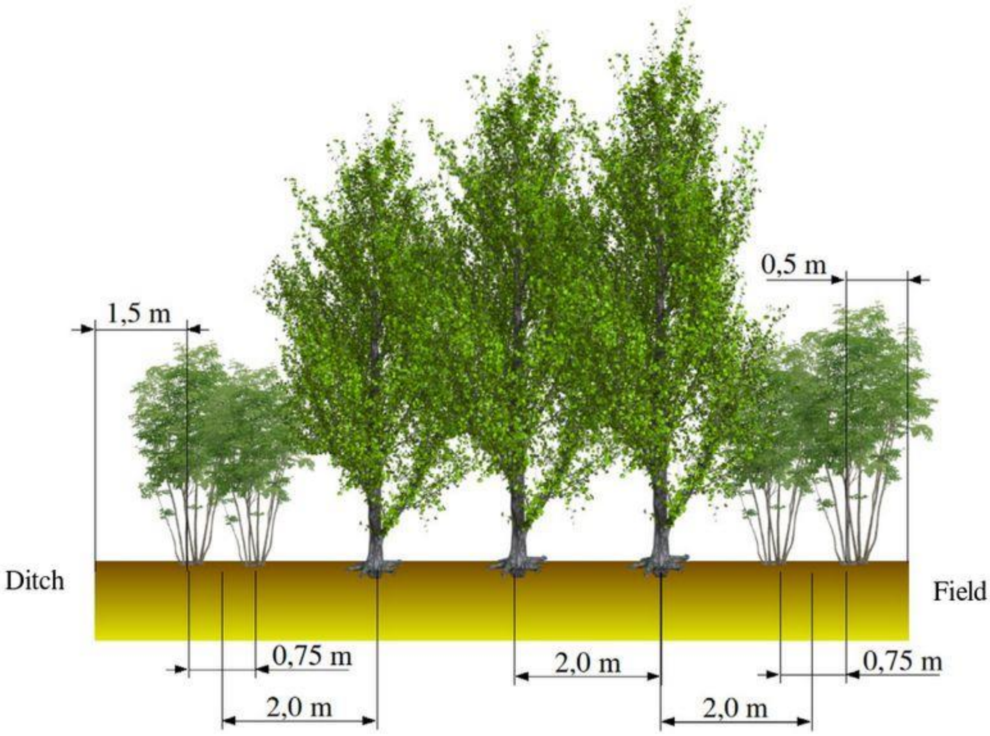


Figure 13. Example of buffer zone consisting of trees and bushes.

3. MEASURES REQUIRING FURTHER INVESTIGATION

3.1 Forestry related measures

3.1.1 Continuous forest cover as a forest regeneration method in spruce stands

In Finland, main attention has so far focused on the regulation of GWT levels, due to the identified contribution of deep drainage to increased CO_2 emissions. The working hypothesis has been put forward that taking advantage of the biological drainage of the tree stand through continuous-cover management, and simultaneously shifting from regular DNM to maintaining only a limited proportion of the ditches, based on catchment-based evaluation, might reduce soil emissions. This is based on an idea that in such management, the GWT remains at a moderate or shallow-drained level (30 cm below the soil surface as in IPCC 2014), which reduces CO_2 emissions but still prevents CH_4 emissions, while being the minimum requirement for sustained forest growth (Sarkkola et al., 2010). Research on such management has started in 2016, but so far there are no published results. One challenge is that a harvesting operation, such as realizing the shift into continuous-cover management, always results in a disturbance in the soil and thus, reduction in the emissions may emerge only after the disturbance impact has passed. In Latvia according to National coniferous forest inventory growing stock in forests with drained organic soils can reach 800 m^3 ha^{-1}. In birch stands with drained nutrient-rich soils growing stock in average is 33% bigger than in forests with wet soils, in spruce stands this difference is 75%. Pine is uncommon in nutrient-rich non-drained soils. In Latvia it was found that both, forests with drained and naturally wet or rewetted organic soils is significant source of GHG emissions and drained forest soils can be either sink or source, depending from the carbon input with plant residues (Butlers, Lazdiņš, et al., 2022; Samariks et al., 2023).

Assumptions on the positive effect initially were based on the studies in Finland (Korkiakoski et al., 2019; Nieminen et al., 2018; Ojanen & Minkkinen, n.d.); however, we realized multiple potential issues in this measure and our recommendation is to continue research, particularly, on the growth impact, potential transfer of emissions due to the increase of harvested areas and increase of risk of natural disturbances. Initial assessment, which requires update, for spruce stands is provided in Table 7 and for pine (strip of spot harvesting), in Table 8. These tables are provided for informative purposes

Table 7. Continuous forest cover as a forest regeneration method in spruce stands

Short description of the action	The scope of the measure is to replace clear-felling with repeated selective felling and formation of uneven age stands. The effect is based on assumption that continuous forest coverage avoids increase of groundwater level and CH_4 emissions from soil. The measure is applicable in management of shade-tolerant species, in Latvia it is only spruce.
CCM impact	CCM impact is not estimated and proved yet. However, the method has been included in national guidelines for good forest management in Finland. The method should be treated equally with conventional management in the revised support scheme that is under evaluation currently. Duration of impact is not verified yet, can be considered as long term in case of strip cleaning and short term in case of selective harvest, because artificial forest regeneration is possible only in strips. Negative effect can be associated

<table>
<tr><td></td><td colspan="3">with distribution of root rot and other forest pests negatively affecting resilience of ecosystems; however no scientific verification is done.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30cm, groundwater at least 30 cm during the growing season</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Current experience in commercial thinning demonstrates significant increase of mortality in spruce stands after thinning sooner or later leading to salvage logging and regeneration of the stand. However there should be potential of strip harvesting in pine stands with following artificial regeneration with pine or birch. Area of clearfellings in Latvia is much smaller than in Finland, therefore, the effect might be much smaller than expected in Latvia, since in small felling site surrounding stands can compensate reduction of evapotranspiration in the felling site. Selective felling considerably increase harvest costs reducing competitiveness of wood deliveries from organic soils and limits possibility to invest in forest regeneration.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs ("+")/benefits ("-"), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>-</td><td>-</td></tr>
<tr><td>Management costs</td><td>-</td><td>-</td></tr>
<tr><td>Income[1]</td><td>3000</td><td>6000</td></tr>
<tr><td>CCM potential</td><td colspan="3">The applicability of the measure is not validated in Baltic states. Up to 1.5 million hectares can be subjected to this measure in Finland. The measure cannot be recommended in Latvia.</td></tr>
</table>

Table 8. Strip harvesting as a forest regeneration method in pine and other sun-lowing tree species stands

<table>
<tr><td>Short description of the action</td><td colspan="3">Actually this measure means reduction of area clear-felling sites by creating of small openings sufficient for regeneration of forest or extraction of long strips (20 to 40 m wide) following with strips of trees. This measure is applicable in forests dominant by tree species, which can't regenerate under canopy of other species (the most of tree species in Latvia except spruce). The measure is aimed to avoid increase of groundwater level and CH_4 emissions after harvesting.</td></tr>
<tr><td>CCM impact</td><td colspan="3">Retaining of low groundwater level ensures that CH_4 emissions are not increasing periodically, while CO_2 emissions from soil remains at initial level and surrounding trees ensures substitution of carbon stock in litter and soil during regeneration of openings or strips.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30cm, groundwater at least 30 cm during the growing season.</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Smaller felling sites increase harvesting and forest regeneration costs and may have negative effect on surrounding stands due to root damages. Smaller openings also increase areas affected by the side effect, where forest regeneration is problematic due to shading of young trees and competition for nutrients.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs ("+")/benefits ("-"), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>-</td><td>-</td></tr>
<tr><td>Management costs</td><td>-</td><td>-</td></tr>
<tr><td>Income[2]</td><td>3000</td><td>6000</td></tr>
<tr><td>CCM potential</td><td colspan="3">The CCM potential is not estimated yet. The threshold values of area of clear-felling sites affected by the increase of groundwater level is not estimated, therefore the measure cannot be recommended for implementation without further investigation.</td></tr>
</table>

3.1.2 Regeneration of forest stand after clear-felling in areas with naturally

[1] Potential incomes due to extraction of currently growing trees as stumpage price.

[2] Potential incomes due to extraction of currently growing trees as stumpage price.

wet organic soils

Forests with naturally wet organic soils are usually regenerated naturally, by seeds and sprouts, thus, the regeneration period is significantly longer in comparison to artificial regeneration, resulting in high CH_4 emission rate, as well as significantly smaller removals of CO_2 in living biomass and other carbon pools. Artificial regeneration ensures additional breeding effect as CO_2 removal (Table 9). Unfortunately GHG measurement data are not available for longer time frame and in this study it assumed that the net GHG emissions from soil equals to the emissions in drained sites because of significantly increased evapotranspiration rate. In spite of increase of CO_2 removals in living biomass by about 100 tons CO_2 during the 70 years rotation period, the conservative approach applied to estimate soil emissions leads to negative mitigation effect; during 50 years period the net emissions increases by 41 tons CO_2 eq ha^{-1}, 0.82 tons CO_2 eq ha^{-1} yr^{-1}. Bioenergy production contributes positively in this period by reduction GHG emissions by 29 tons CO_2 eq ha^{-1} yr^{-1}. In optimistic scenario, assuming that the awaited additional increment is reached and GHG pattern differences observed in the demo sites will continue or will return to the level of the fluxes typical for wet organic soils, the net emission reduction in 50 years period would reach about 80 tons CO_2 eq. ha^{-1}. Further studies are necessary to evaluate effect of this measure.

Table 9. Regeneration of birch or alder after clear-felling in areas with naturally wet organic soils

<table>
<tr><td>Short description of the action</td><td colspan="3">Grey and black alder, as well as birch, are tree species with the highest level of tolerance to periodic flooding while retaining high productivity by planting trees on mounds and improvement of surface drainage to avoid losses due to natural disturbances caused by periodic increase of groundwater level. Planting of trees on mounds also reduces duration of forest regeneration period when carbon losses significantly exceeds removals.</td></tr>
<tr><td>CCM impact</td><td colspan="3">The CCM effect is associated with increase of CO_2 removals in living biomass and other carbon pools including harvested wood products (HWP) due to faster growth. Mounding and shallow drainage furrows ensures that upper soil layers are continuously aerated thus avoiding CH_4 emissions. However, effect of the measure is not scientifically proved yet. Assuming that growth rate after implementation of the measure changes from values typical for wet forests to values characteristic in drained soils, the net emission reduction reach 9,9 tons CO_2 eq. ha^{-1} yr^{-1} during 120 years period; however, this effect is diminished by natural disturbances and limitations in local conditions.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Lower bog peat soil, peat layer thickness at least 30 cm, during the groundwater vegetation season higher than 30 cm, the dominant species black alder or birch, stand age or diameter of stand trees has reached the limit values specified for regeneration felling.</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Natural disturbances (periodic increase of groundwater level) may limit or completely diminish climate change mitigation effect and result in significant economic losses. Improvement of water regime might be problematic in many cases due to inappropriate terrain.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs (“+”)/benefits (“-”), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment[3]</td><td>1500</td><td>300</td></tr>
<tr><td>Management costs</td><td>-</td><td>900</td></tr>
<tr><td>Income</td><td>-</td><td>8000</td></tr>
<tr><td>CCM potential</td><td colspan="3">CCM potential is not estimated yet, additional CO_2 removals may reach 20% or more depending from local conditions and possibilities to improve water regime.</td></tr>
</table>

[3] Additional forest regeneration costs comparing natural and artificial regeneration.

3.1.3 Artificial regeneration of coniferous forest stands areas with naturally wet sites

Another option of artificial regeneration of naturally wet organic soils in forest lands in planting of spruce or pine on mounds, ensuring that trees have favourable growth conditions during the first year of development. The artificial regeneration ensures additional breeding effect as CO_2 removal in living biomass. In this study it assumed that the net GHG emissions from soil in case of artificial regeneration equals to the emissions in drained sites because of significantly increased evapotranspiration rate (Table 10). In contrast to deciduous forests with naturally wet soils this measure have positive effect even using conservative approach for calculation of soil GHG fluxes, in 50 years period the net emissions reduces by 148 tons CO_2 eq ha^{-1}, 2.95 tons CO_2 eq ha^{-1} yr^{-1}. Bioenergy production contribution is negligible in 50 years period, but significantly increase after 80 years. In spite the measure results in significant GHG mitigation and has considerable implementation potential, it is also associated with different risks of natural disturbances; therefore during the regeneration stage it is important to establish remedial drainage system to ensure that trees are not suffering from exceeding amount of water during the early development stage.

Table 10. Artificial regeneration of coniferous forest stands areas with naturally wet sites

<table>
<tr><td>Short description of the action</td><td colspan="3">Mounding, improvement of water regime and use of high quality planting material ensures increase of CO_2 removals in living biomass in forests with naturally wet organic soils, where natural forest regeneration methods results in low quality stands.</td></tr>
<tr><td>CCM impact</td><td colspan="3">The climate change mitigation effect in optimal conditions reach 5.8 tons CO_2 eq. ha^{-1} yr^{-1} (694 tons CO_2 eq. ha^{-1} in 120 years period). This estimate considers reduction of carbon losses and GHG emissions from soil and additional removals in living biomass due to improvement of water regime and shorter forest regeneration period.</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient-rich organic soil, peat layer sickness at least 30 cm, groundwater above 30 cm during the growing season</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Natural disturbances may diminish effect of the measure and result in economic losses. Local terrain conditions may not be favourable to improve water regime, therefore, CH_4 emissions remains high. Many areas, where the measure can be implemented, are subject of different management restrictions; therefore, the real potential is significantly smaller than the theoretical estimates.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs ("+")/benefits ("-"), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>1500</td><td>300</td></tr>
<tr><td>Management costs</td><td>-</td><td>900</td></tr>
<tr><td>Income</td><td>-</td><td>8000</td></tr>
<tr><td>CCM potential</td><td colspan="3">CCM potential is not estimated since activity data (groundwater level maps) are not developed to the level necessary to model emissions under different management regimes. The total emission reduction potential in Latvia is about 1 mill. tons CO_2 eq. yr^{-1}.</td></tr>
</table>

3.1.4 Regeneration of riparian buffer zone in forest land with black alder or birch

Shelter belts can also be planted in forest lands in or nearby the protective zones of water bodies or alluvial areas. Such areas are usually regenerated naturally, by seeds and sprouts, thus, the regeneration period is significantly longer in comparison to artificial regeneration, resulting in high

CH_4 emission rate, as well as significantly smaller removals of CO_2 in living biomass and other carbon pools. Artificial regeneration by establishment of shelter belts of water tolerant tree species ensures additional breeding effect as CO_2 removal. GHG measurement data are not available for longer time frame for such areas and in this study it assumed that the net GHG emissions from soil equals to the emissions in drained sites, just like in case of artificial regeneration of grey alder stands. Using the conservative approach applied to estimate soil emissions the mitigation effect is negative; during 50 years period the net emissions increases by 41 tons CO_2 eq ha^{-1}, 0.82 tons CO_2 eq ha^{-1} yr^{-1}. Bioenergy production contributes positively in this period by reduction GHG emissions by 29 tons CO_2 eq ha^{-1} yr^{-1}. In optimistic scenario, assuming that the awaited additional increment is reached and GHG pattern differences observed in the demo site will continue or will return to the level of the fluxes typical for wet organic soils, the net emission reduction in 50 years period would reach about 80 tons CO_2 eq. ha^{-1}. Further studies are necessary to evaluate effect of this measure; however, implementation potential of this measure is limited due to forest management restrictions in the alluvial areas. Preliminary information on this measure is provided in Table 11.

Table 11. Regeneration of riparian buffer zone in forest land with black alder or birch

Short description of the action	Management of riparian zones is aimed to utilize nutrients approaching to the water bodies from surrounding forest stands and agricultural soils. Better soil scarification methods, planting material and improved water regime by establishment of network of shallow furrows increases capability of plants to utilize nutrients and exceeding soil water. Managed buffer zones are bends of trees around water streams.		
CCM impact	Climate change mitigation is associated with CO_2 removals in living biomass and reduction of CH_4 emissions from soil. The net impact is not yet estimated however, significant improvement of stand composition and growth rate would result in net reduction of GHG emissions by 1.2 tons CO_2 eq. ha^{-1} yr^{-1} (148 tons CO_2 eq. ha^{-1} in 120 years period). The removals of CO_2 in living biomass is compensated partly by increased carbon losses from soil.		
Area characteristics	Nutrient-rich organic soil, peat layer sickness at least 30 cm, groundwater above 30 cm during the growing season.		
Any associated risks or potential implementation obstacles	Management of buffer zones is restricted by legal acts prohibiting clearfellings and other management activities around water streams, therefore trees can be planted at certain distance from the water streams significantly decreasing areas suitable for this measure.		
Costs and benefits associated with implementation of the action	**Cost/benefit position**	**Costs ("+")/benefits ("-"), EUR ha^{-1}**	
		1st year	**Next years**
	Investment	1500	300
	Management costs	-	900
	Income	-	8000
CCM potential	CCM potential is not estimated yet due to limited information on CH_4 emissions and area potentially suitable for establishment of buffer zones.		

3.2 Agricultural lands related measures

3.2.1 Controlled drainage of grassland

In our study we did not observed reduction of GHG emissions from soil after implementation of controlled drainage in grassland. Due to slight increase of CO_2 and CH_4 emissions in the area with regulated groundwater level the net emissions from the area increased; however, this increase is negligible – 27 tons CO_2 eq ha^{-1} during 50 years period. Further studies are necessary to evaluate long term effect of the groundwater level regulation. The short term increase may be associated with improved water regime in summer resulting in an increase of CO_2 emissions. It is also important that we used in the calculation average carbon input with plant residues, while better water regime during summer may be also associated with bigger biomass production rate. Further studies are necessary to evaluate these factors. Initial assumptions of effectiveness of this measure are provided in Table 12.

Table 12. Controlled drainage of grassland

Short description of the action	Groundwater regulation systems ensures retaining of certain groundwater level, e.g. 30 cm ensuring relative low CH_4 ans CO_2 emissions from organic soils. The measure can be used both, in cropland and grassland.		
CCM impact	Duration of the impact equals to period of implementation of the measure and life-time of drainage systems. Total impact of the measure is not estimated.		
Area characteristics	Nutrient-rich organic soil, peat layer sickness at least 30 cm, groundwater at least 30 cm during the growing season.		
Any associated risks or potential implementation obstacles	Data on the emission reduction are not verified by scientific evidences therefore climate change mitigation potential may be overestimated. The terrain conditions in the most cases are not suitable for establishment of controlled drainage systems.		
Costs and benefits associated with implementation of the action	**Cost/benefit position**	**Costs ("+")/benefits ("-"), EUR ha^{-1}**	
		1st year	**Next years**
	Investment[4]	1200	-
	Management costs	-	-
	Income	-	-
CCM potential	Implementation potential, as well as cost-benefit ratio at a national scale is not estimated yet. No controversial impacts are known with the sustainability criteria. The measure may have adverse impact on accessibility of fields during spring and summer season; however, limited data are available on impact of different strategies in regulation of drainage systems.		

4 Depends on area. Current estimate is based on 3 ha field.

3.2.2 Introduction of legumes in conventional farm crop rotation

(Wang et al., 2019).

Table 13. Introduction of legumes in conventional farm crop rotation

<table>
<tr><td>Short description of the action</td><td colspan="3">Introduction of legumes into crop rotation in farmland managed in accordance with good practice guidelines for integrated farms. Legumes are sawn in rotation with cereal crop.</td></tr>
<tr><td>CCM impact</td><td colspan="3">GHG emission reduction related to the decrease of N20 and CO2 emissions from soil. Additional biomass – carbon sequestration, reduced nitrogen - effect results from the substitution of synthetic nitrogen fertilizers by biological nitrogen fixation</td></tr>
<tr><td>Area characteristics</td><td colspan="3">Nutrient- rich organic soil, peat layer sickness at least 30 cm, groundwater at least 30 cm during the growing season. Area – managed as cropland.</td></tr>
<tr><td>Any associated risks or potential implementation obstacles</td><td colspan="3">Risks: 1) farmers continue usual fertilizing practice without considering legume effect – because of the lack of knowledge; 2) GHG reduction is not reflected in National GHG inventory report because of the lack of necessary data.</td></tr>
<tr><td rowspan="5">Costs and benefits associated with implementation of the action</td><td rowspan="2">Cost/benefit position</td><td colspan="2">Costs (“+”)/benefits (“-”), EUR ha^{-1}</td></tr>
<tr><td>1st year</td><td>Next years</td></tr>
<tr><td>Investment</td><td>-</td><td>-</td></tr>
<tr><td>Management costs</td><td>-</td><td>-</td></tr>
<tr><td>Income</td><td>-</td><td>-</td></tr>
<tr><td>CCM potential</td><td colspan="3">From scientific literature: Increased legume share in crop rotations is recognized as climate change mitigation measure. NO3 (plus ammonium and nitrite) leaching losses would be reduced by up to 20%. There would be associated reduction in direct (up to 50%) and indirect (up to 20%) N2O emissions, and NH3 emissions (c.50%) (Newell Price, J.P., et al., 2011). Annual mitigation potentials are quantified between 0.5 and 1 t CO_2 equivalents per hectare for Great Britain through increased use of nitrogen fixation of clover and introduction of additional species (including legumes) in crop rotations (Rees, R.M., et al., 2013).
National report: According to the IPCC guidelines, after introduction of legumes in crop rotation the management system in the affected fields would be changed to “High, without manure” due to increased input of organic materials and the carbon stock change factor for input will increase to 1.11. 20 years’ transition period is considered in calculation of soil carbon stock changes. Implementation of the measure according to the tier 1 method will contribute to the net CO2 removals in soil –1.32 tonnes CO^2 ha^{-1} annually (26.4 tonnes CO_2 ha^{-1} in total) during 20 years’ period. Carbon sequestration in soil (0-30 cm depth) after 20 years transition period would increase from 65.6t C ha^{-1} to 72.8 t C ha^{-1}.</td></tr>
</table>

CONCLUSIONS

Transformation of arable land with drained organic soil into grassland can significantly reduce GHG emissions and it is less costly measure; however, it's effect is significantly smaller than the mitigation effect of afforestation. It has also limited implementation potential since rather limited area of farmlands with organic soils are still used as cropland. This measure can be recommended for national climate policies, but more efficient measures should be considered instead.

Afforestation of organic soils in cropland and grassland with birch, spruce, pine and black alder, and retaining of drainage systems provides the best combination of the mitigation effect and limited level of risk of the natural disturbance. Additional effect can be ensured by periodic application of wood ash to increase the stock of potassium, phosphorus and other cations in soil. Breeded planting material should be used in forest regeneration to ensure continuous mitigation effect. This measure should be prioritized in climate plans.

Afforestation of farmlands with organic soil with following rewetting is another measure with significant mitigation, as well as the implementation potential; however, it is also associated with higher risk of natural disturbances and theoretical mitigation potential can be significantly reduced due to the disturbances and different growth limiting factors. Remedial or temporal ditching is important during the afforestation stage to reduce this risk. The temporal ditching also can help to implement short term climate change mitigation and long term biodiversity targets. This measure can be recommended for climate policies; however, the implementation risks should be considered.

Use of wood ash in forest stands with drained organic soil after thinning is efficient and fast acting measure ensuring significant additional CO_2 removals in living biomass and other carbon pools in short period of time. This measure is one of the few contributing to implementation of short term, as well as long term mitigation measures. This measure is recommended for implementation of the national climate targets. It should be planned in conjunction with use of renewable forest biofuel in energy sector.

Plantations of woody crops (short rotation forests) in arable land with drained organic soil for timber and biofuel production is the most efficient climate change mitigation measure; however, it is also the most expensive and associated with bigger risk of natural disturbances. Short rotation forests requires protection and more attention during the regeneration stage than the afforestation related measures. This measure can be recommended for national climate plans, but the additional measures should be considered to reduce potential implementation risks. The research should be continued to improve management methods, to select right breeds and to increase outputs of sawn materials.

Planting of fast-growing tree species in shelter belts around drainage systems in farmlands with organic soils have similar potential effect as short rotation forests; however, it can be even more expensive in the implementation stage. This measure can also be recommended for the national climate plans; however, it's implementation potential is limited due to possibility to afforest and to grow short rotation forests in organic soils.

Use of legumes in plant rotation in arable land with drained organic soil and controlled drainage in grassland with organic soil did not demonstrated significant mitigation potential in our studies. Similarly, no significant positive effect of strip felling in a pine stands was. These measures requires further investigations before recommendation for implementation in the national climate and energy programs.

Selective felling in spruce stands demonstrated positive effect on GHG emissions from soil; however, this effect can be neglected by the fact that logging area should be increased at least three times to acquire the same amount of wood, and cumulative emissions from such, extended area may be even bigger than from smaller clear-felling site. Additionally, selective felling is associated with the increased risk of natural disturbances, it makes impossible artificial regeneration, thus loosing breeding effect (15-20% of additional removals in living biomass) and it can contribute to negative selection by leaving weaker and removing stronger trees during felling. Strip or spot harvesting in spruce stands should be evaluated further to evaluate if the effect of the mitigation of emissions from soil is retained in the smaller, e.g. 0.5 ha, openings.

Artificial regeneration with black alder, birch, pine or spruce stands in areas with naturally wet soils by planting trees on mounds and establishing network of furrows to remove exceeding water from topsoil layer seems to be promising solutions; however, this measure is associated with bigger risk of natural disturbances. Proper risk management is the key element for success during the implementation stage. Further observations are necessary to evaluate the effect on soil GHG fluxes after regeneration and the potential negative effect of natural disturbances and growth limiting factors. Additional efforts should be paid to elaborate spatial tool for selection of forest stands suitable for implementation of this measure and development of remedial drainage system and network of furrows.

Planting of black alder or birch shelter belts in alluvial zones in forested areas with organic soil seems to be efficient forestry measure; however, selection of suitable areas is more complicated than for other measures, particularly, because of management restrictions having potential negative effect on long term carbon storage in HWP and the substitution effect. This measure also requires further investigation to evaluate effect of the soil GHG fluxes. Combination of this measure and artificial regeneration of forests in areas with wet organic soils can be implemented in regeneration of wet forests by planting black alder or birch in terrain depressions, where probability of survival of coniferous trees is significantly smaller; thus this measure would also contribute to increase of biodiversity.

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