 DOI: 10.22616/rrd.28.2022.008

REVIEW OF CLIMATE CHANGE MITIGATION MEASURES APPLICABLE IN DEGRADED PEATLANDS IN LATVIA

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Abstract
Former peat extraction fields and currently employed peatlands are significant source of GHG emissions. Total area of degraded peatlands, which are not yet afforested or flooded is 39.5 kha and the net emissions, excluding peat produced for the horticulture applications, is 0.33 mill. tons CO_2 eq. Large emissions means also significant mitigation potential; therefore, available knowledge on the GHG mitigation potential should be summarized to define research priorities and propose quantifiable measures.
The aim of the study is to summarize literature and expert questionnaires based information on potentially valuable climate change mitigation measures applicable in degraded peatlands formerly used for peat extraction. The evaluation involves substantiation of the effect, criteria for site selection, addressed carbon pools and GHG emissions, methods for the effect assessment at local and national level, existing LPIS and other monitoring systems, duration of effect and supplementary measures to sustain the effect, estimation of cost and benefit ratio, existing support schemes, knowledge gaps to be filled, uncertainties and collaboration needed.
The study proved that degraded peatlands can contribute significantly to the climate change targets, and this is identified by scientific community in multiple publications and research reports; however, quantitative assessment is missing in most of the cases. The most of the proved mitigation measures are associated with afforestation, which can be implemented in approximately 50% of degraded peatlands.
Key words: greenhouse gas, GHG, emissions, degraded peatlands, mitigation measures.

Introduction

According to the guidelines of Intergovernmental Panel on Climate Change (IPCC), Latvia is located in a temperate cool & moist (TCM) climate zone. Organic soils in the TCM region is a significant source of greenhouse gas (GHG) emissions. In Latvia, organic soils contribute to 100% of GHG emissions from cropland and grassland in land use, land use change and forestry (LULUCF) sector (Ministry of Environmental Protection and Regional Development, 2021). The total area of organic soils, usually not separated into nutrient-rich and -poor soils in the National GHG inventory reports, in the project partner countries is 17 mill. ha, representing 48% of organic soils in the EU and 75% of organic soils in TCM climate zone (Līcīte *et al.*, 2019). GHG emissions from organic soils in the EU is 117 mill. tons CO_2 eq. including 32 mill. tons CO_2 eq. (27% form the EU GHG emissions from organic soils) in the participating countries). GHG emissions from organic soils are characterized by high uncertainty rate and significant differences between countries in the same climate zone (Lupiķis & Lazdins, 2017).

In Latvia, 41.3% of total organic soils are occupied by forests, 40.1% – by wetlands (excluding peat extraction areas and flooded wetlands), 9.6% – by cropland, 5.0% – by grassland, 3.2% – peat extraction areas and 0.7% by flooded and rewetted wetlands (Līcīte *et al.*, 2019). Emission factors used to calculate carbon stock changes in organic soils in different

Table 1

Emission factors used to calculate carbon stock changes in organic soils in different land use types in Latvia (Ministry of Environmental Protection and Regional Development, 2021)

Land use		Net carbon stock change in organic soils per area, t C ha^{-1}
Category	Sub-category	
Wetlands	Wetlands remaining wetlands (average)	-0.22
	Peat extraction remaining peat extraction	-2.80
	Flooded land remaining flooded land	Included elsewhere (IE)
	Other wetlands remaining other wetlands	Not applicable
	Land converted to wetlands (average)	-2.27
	Land converted to peat extraction	Not applicable
	Land converted to flooded land	IE
	Land converted to other wetlands	-2.71

Table 2

Emission factors for calculation of emissions from drainage and rewetting and other management of organic soils in Latvia (Ministry of Environmental Protection and Regional Development, 2021)

Type of soil	Emission factors			
	CO_2, tons CO_2 ha^{-1}	N_2O-N, kg N_2O-N ha^{-1}	CH_4, kg CH_4 ha^{-1}	CH_4, kg CH_4 ha^{-1} from ditches
Peat extraction fields	1.21	0.44	10.83	542.00
Rewetted and flooded organic soils	0.50	-	216.00	-

wetland categories within National GHG Inventory 2021 are summarized in Table 1.

Emission factors for calculation of emissions and removals from organic soils in wetlands in Latvia are summarized in Table 2. In rewetted and flooded lands default emission factors are applied. Country specific emission factors are elaborated for peat extraction fields and other drained, nutrient poor soils (Lazdiņš & Lupiķis, 2019).

Climate change mitigation targeted measures applied to managed organic soils reported by Latvia under Article 10 of the LULUCF Decision and listed in the Reports on Policies and Measures under Article 13 and on Projections under Article 14 of Regulation (EU) No 525/2013 of the European Parliament and of the Council are based on the Latvian Rural Development Programme 2014-2020. No measures are directly addressed to restoration of wetlands; however, afforestation is often listed as the most valuable climate change mitigation measure (Upenieks & Rudusāne, 2021). Information about rewetting is controversial; according to earlier studies in Latvia

Table 3

Contents of experts questionnaire about climate change mitigation targeted measures

No	Type	Description
	Title	Simple and short title describing core of the measure.
	Substantiation of the impact	Brief description of impact of the measures.
	Criteria for site selection	Criteria for selection of suitable sites where the selected measures can be implemented to ensure the proposed effect.
	Addressed carbon pools and GHG emissions	Carbon pools and GHG fluxes positively or negatively affected by the measure.
	Methods and models applied for impact assessment at local and national level	Existing calculation methods including assumptions for listing the measure under GHG emissions reduction targeted activities.
	How existing land parcel information system (LPIS) and other monitoring systems should be improved to verify the impact	Existing and necessary activity data sources on carbon stock changes, which can be used in calculations.
	Duration of impact and supplementary measures to sustain the impact	Duration of the impact of the measure, additional activities necessary to maintain the achieved mitigation effect or to ensure that the proposed impact will be achieved.
	Quantitative implementation potential at a national level	Quantitative impact assessment – tons CO_2 eq ha^{-1} and at national level, different pools can be evaluated separately, as well as pools missing information on climate change mitigation can be added.
	Conformity with sustainability criteria	Conformity with sustainability criteria listed in the LULUCF regulation and national policies.
	Estimation of cost and benefit ratio	Information on implementation costs, investments and potential financial outcome by selling of wood.
	Interferences and synergies with other sectors, land uses and policies	Description of impact on other sectors, e.g. agriculture or energy sector.
	Knowledge gaps to be filled, uncertainties, collaboration needed	Missing knowledge on the impact of the measure, application area, activity data sources and monitoring tools to follow up to implementation of the measure.

and Finland, rewetting may not decrease emissions, at least in short term (Butlers *et al*., 2021; Ojanen & Minkkinen, n.d.).

The aim of the study is to summarize literature and expert questionnaires based information on potentially valuable climate change mitigation measures applicable in degraded peatlands formerly used for peat extraction.

Materials and Methods

The review is based on the expert questionnaires and literature studies. Expert questionnaire is used to identify potential measures. Questions asked to experts and reviewed in the scientific literature are listed in Table 3. Seven experts or expert teams from Latvia, Lithuania, Estonia, Finland and Germany were involved in completion of the questionnaire. The most of the experts providing answers are involved in the GHG inventory process.

Results and Discussion

Climate change mitigation measures in former peat extraction fields are mostly associated with afforestation and management of afforested lands or rewetting; however, verified quantitative information is available only for forest management related activities. Mitigation measures are grouped into land use changes, forest products, productivity, risk management and other forest management related measures in Table 4, highlighting (by bolding) the description of the most critical measures.

The most of the measures having proved mitigation potential require afforestation of degraded peatlands. This is realistic scenario in about half of the

Table 4

Identified climate change mitigation measures

Group	Title of measure
Land use changes	**Afforestation of former peat extraction fields**
	Conversion of peat extraction fields into woody paludicultures for HWP and biofuel production
	Intensive cultivated short rotation forests in peat extraction fields
	Rewetting of peatlands – conversion to wetlands
Forest products	Improved bucking instructions, laser scanning and image analysis technologies to improve the output of assortments
	Increase efficiency of utilization of timber – less biofuel and pulpwood and more harvested wood products
	Introduction of low impact logging technologies to avoid formation of methane hotspots and distribution of root rot
	More efficient harvesting technologies to reduce timber damages
Forest management	Rewetting of low valued drained forests with limited growth potential
	Continuous-cover forestry
Increasing productivity	Adaptation of drainage systems to optimal depth of groundwater and inflow
	Application of mineral fertilizers and shortening of rotation
	Drainage and intensification of forest management on fertile wet organic soils
	Fertilization with wood ash
	Improvement of genetic properties and adaptiveness of planting material and forest regeneration methods
	Introduction of innovative soil scarification methods and improved planting material
	Pre-commercial thinning
	Remedial ditching to enhance regeneration of forests with wet soils
Risk management	Avoiding degradation of natural surface water flows during thinning and regenerative felling
	Elimination of hotspots of methane emissions – establishment of shallow ditch network to ensure aeration of topsoil layer
	Fire prevention – mineralized belts, early warning systems, better equipment
	Prevention of wind throws and snow-break risk by intensified rotations and more resilient stands
	Reduction of risk of distribution of pests by increase of resilience of forest stands
	Slowing down of root rot distribution

degraded peatlands (Lazdiņš, 2022), while the rest can be rewetted or flooded because of high groundwater level under natural conditions. Afforestation is only the 1st step of the climate change mitigation. Further actions are necessary to increase the mitigation effect and to ensure resilience of afforested areas. The most critical measures in afforested sites are proper soil preparation (large mounds and network of furrows to avoid methane emissions), use of appropriate planting materials, fertilization with wood ash or complex fertilizers (repeated application before afforestation and after every thinning should be considered), wildfire prevention measures and gradual felling (continuous-cover forestry) as a way of forest regeneration. Other measures listed in Table 4 can enhance the mitigation effect if the most critical measures are implemented.

Improved planting material increases productivity and resilience of future forests. The effect can be estimated using forest growth models assuming additional relative increments in the areas where improved material is used. Detailed estimates are not yet possible. Stand wise forest inventory data can be used to locate areas where the measures are implemented to obtain local level activity data. National LPIS system needs to be improved to keep the track of areas where the measures are implemented. Additional measures which should be implemented are early tending, thinning and forest protection. Fertilization is basically mandatory. Additional costs in current prices is about 450 € ha^{-1} (planting material, soil scarification and planting or sowing) in current prices. Average price per ton of CO_2 in current prices is 6.1 € ton^{-1} CO_2 (Līcīte *et al*., 2019). Considerable additional increment and outputs of roundwood and forest biofuel will create significant input to energy sector and wood processing industry. Higher yields and more active forest regeneration would increase fuel consumption in forest operations, which can reach 5% of the CO_2 output with biofuel and wood logs. The measure can positively interfere with climate change adaptation policy (Lazdiņš *et al*., 2015). There is general remark in national forest policy of Latvia that forest management should ensure that forest value is not decreasing; however, there is no direct support to forest regeneration.

Mounding is soil scarification method which is more and more commonly used in forestry. Long term effect of this measure is not yet evaluated; especially, reduction of losses due to natural disturbances. The long term effect depends on further forest management steps, particularly, on timely implemented thinning and regenerative felling. Impact on soil GHG fluxes needs to be evaluated (Dzerina *et al*., 2016). Stand wise forest inventory can provide information on areas where this measure is contributing to additional CO_2 removals at a local and national scale. The projections highly depend on early management and probabilities of different development scenarios. These probabilities need to be developed to create projections at a national level. A short term impact, which can be relatively easily estimated just by assuming faster growth of planted trees is relatively small and does not have a significant impact on carbon stock changes in a short term. The measure has continuous impact during the lifetime of the forest stand. The impact of the measure accumulates through several rotations and can be increased by application of other measures like remedial drainage, maintenance of drainage systems and fertilization. Implementation of this measure increases resilience and potential value of forests on nutrient-rich soils contributing to implementation of sustainability criteria associated with forest value. Mounding increases soil scarification cost by about 150 € ha^{-1}; however, it can also contribute to reduction of cost during early tending and pre-commercial thinning. Conventional management systems need to be updated to utilize the potential of fertile forest soils more efficiently. This measure is not supported; however, there is a proposal to consider support for purchasing of planting machines in the Rural Development Program 2021-2027, which will boost application of mounding in forest regeneration.

Application of mineral fertilizers is identified as potentially the most valuable method in Latvia to reach 2030 targets. It is also supported by the government in Norway. Linear additional increment rates are considered according to the applied dosage of fertilizer assuming that forest management is optimized to ensure the additional increment (Petaja *et al*., 2018). The estimation of long term impact of changes in forest management is not yet done; therefore, only a short term impact is considered. Stand wise forest inventory data can be used to estimate carbon stock changes at local and national level. However, national LPIS does not provide information on application of fertilizers. Projections of long term effect can be verified by application of remote sensing (vegetation indexes, LiDAR) data. Short term effect continues for 10-20 years; long term effect continues during the whole rotation, especially if it is associated with changes in the management regime. No additional measures are necessary to ensure the short term effect; ensuring the long term effect requires following to the good practice guidelines in thinning, regenerative felling and maintenance of drainage systems.

Fertilization cost is 160 € ha^{-1} according to a price level in 2017. Cost of CO_2 removals, if the short term impact is considered, equals to 8 € ton^{-1} CO_2 eq. (Bērziņa *et al*., 2018). Fertilization increases N_2O emissions from soil; however, this effect is far less than the net removals (Okmanis *et al*., 2018; Petaja *et al*., 2018). No support is considered for fertilization in national legislation; however, it is not restricted either.

Wood ash recycling is another type of fertilization, which can be combined with mineral fertilizers to substitute expensive P and K mineral fertilizers and can be added alone in moderately rich soils not suffering from shortage of nitrogen. Linear additional increment (around 15 m^3 ha^{-1} per treatment) is considered in several studies assuming that the forest management is optimized to ensure the additional increment (Okmanis *et al*., 2018; Okmanis, Lazdiņš *et al*., 2015; Okmanis, Polmanis *et al*., 2015). There are no models elaborated for Latvia to estimate impact of changes in the forest management; therefore, only a short term impact is considered. National LPIS does not provide information on application of wood ash; therefore, reporting of forest fertilization with wood ash at a stand wise level should be implemented. These data can be utilized in stand wise inventory to report additional CO_2 removals. A short term impact continues for 10-20 years; a long term impact continues during the whole rotation, especially if it is associated with changes in the management regime. No additional measures are necessary to ensure a short term effect; a long term effect requires following to good practice guidelines in thinning, timely regenerative felling and maintenance of drainage systems. Commercially more valuable species (birch, spruce, pine) have to be planted instead of low quality stands. Fertilization cost in Latvia in 2017 was 120 € ha^{-1}. Cost of CO_2 removals, if short term impact is considered, equals to 6 € ton^{-1} CO_2 eq (Petaja *et al*., 2018). No support is considered for wood ash recycling in forests in national legislation in Latvia.

Methane hotspots are terrain depressions with high groundwater level, which are usually significant source of CH_4 emissions. Terrain data analysis based tools can be used to identify potentially affected area. Growth models can be used to determine additional CO_2 removals in living biomass and other carbon pools. Wet areas cannot be easily identified because of outputs of groundwater creating depressions in areas where the models driven by precipitation and terrain data cannot find any depression. Existing LPIS system needs to be improved and supplied with maps characterizing 'wetness', respectively, information necessary to identify hotspots of CH4 emissions (Melniks *et al*., 2019). Digging up to 30 cm deep ditches in forest is in line with national regulations and does not require permission. Cost benefit ratio of the measure is not yet estimated. The measure is not supported in national policies; however, considering contribution to CH_4 and Hg reduction (Bishop & Lee, 1997; Lidskog *et al*., 2018), this measure has a significant implementation potential.

Fire prevention is especially important for organic soils, and it is critical to retain carbon pools developed by other measures. Methods for quantitative assessment are not developed yet, because it is complicated to predict amount of soil organic matter incinerated during forest fires. LPIS can be used to estimate risk of forest fires; however, the effect of the measure cannot be easily verified. Quantitative impact on the GHG emissions is not evaluated yet in Latvia; however, the importance of this measure is recognized. Cost benefit ratio is not estimated yet in Latvia. Prevention of forest fires avoid emissions of harmful substances like PAHs and dioxins, thus contributing to maintenance of healthy environment. In Latvia, maintenance of fire prevention systems is supported at national level by the Rural development program. Continuous development and automation of the system ensures more efficient identification of forest fires and continuous avoiding of the GHG emissions due to forest fires (Ministry of Agriculture, 2018).

Gradual regenerative felling is aimed to reduce an increase of groundwater level and following CH_4 emissions after felling, and it is identified as potentially valuable measure in Finland and Latvia with ongoing research activities in Finland. Activity data may be obtained from harvesting reports collected by forest authorities. Active management is required for a long-term impact. Cost – benefit ratio is not available yet (Korkiakoski *et al*., 2019; Nieminen *et al*., 2018; Ojanen & Minkkinen, 2019).

In Latvia, in spite of potential benefits of this method, quantitative assessment, even at experimental scale is not done due to multiple constrains, e.g. root rot distribution in spruce stands and unpredictable impact of different stress factors. Current experience in commercial thinning demonstrates a significant increase in mortality in spruce stands after thinning sooner or later leading to salvage logging and regeneration of the stand (Līcīte *et al*., 2019). However, there should be potential of strip harvesting in pine stands with following artificial regeneration with pine or birch. Stand wise forest inventory data can be used to locate areas where the measure is implemented to obtain local level activity data. National LPIS system needs to be improved to keep track of areas where the measure is implemented. Remote sensing related methods can be developed to monitor and verify growth; however, scientific approval of this method needs to be developed at first. Duration of effect is not verified yet, and can be considered as a long term measure in case of strip cleaning and a short term in case of selective harvest, because artificial forest regeneration is possible only in strips. Quantitative effect also is not estimated yet. The measure is not supported by specific legal acts but can be applied voluntary by a forest owner. Selective harvests of pine are mandatory in coastal areas; however, degraded peatlands are minor in these areas.

It is important to point out that former peat extraction fields are usually located in nutrient poor soils with limited growth potential; therefore, GHG mitigation potential in these areas is relatively small, and biodiversity targets might be prioritized to implement mitigation measures in other, more fertile lands, e.g. organic soils in cropland and grassland by substitution of biologically valuable areas with rewetted peatlands.

Conclusions

1. The potential role of the degraded peatlands in implementation of the climate change targets is identified by scientific community in multiple publications and research reports; however, controversial results, e.g. on rewetting or conversion to grassland, highlights knowledge gaps and missing activity data.
2. National policy and climate change mitigation strategy recognize the role of organic soils in the reduction of GHG emissions; however, only afforestation may have an indirect impact assuming that certain proportion of the afforested areas will have organic soils.
3. Mitigation measures in national policies usually lack quantitative assessment and quantitative targets. The implementation requirements, e.g. moisture regime or soil type, may no be sufficiently detailed thus significantly increasing uncertainty of the impact assessment.
4. The most of the measures are not soil specific; however, the impact, as well as the implementation conditions may differ for mineral and organic soils. The quantitative impact can be estimated for land use and management system changes related measures; however, the uncertainty rates are high.
5. National LPIS system, as well as soil and moisture maps should be improved to ensure ability to estimate and to project the impact of the proposed climate change mitigation measures. Country specific methodologies should be elaborated to ensure efficient use of resources for the emission reduction in degraded wetlands.

Acknowledgements

The study is implemented within the scope of the project European Regional Development Fund Project ‘Development of greenhouse gas emission factors and decision support tools for management of peatlands after peat extraction’ (No. 1.1.1.1/19/A/064).

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