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

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ACTIONS

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SUMMARY

Organic soils is significant source of greenhouse gas (GHG) emissions in the temperate cool & moist (TCM) climate zone according to the National GHG inventory reports, specifically, organic soils may contribute to 100% of GHG emissions from cropland and grassland in land use, land use change and forestry (LULUCF) sector. 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 EU and 75% of organic soils in TCM climate zone. GHG emissions from organic soils in EU is 117 mill. tons CO_2 eq. including 32 mill. tons CO_2 eq. (27% form EU GHG emissions from organic soils) in the participating countries). GHG emissions from organic soils characterizes with high uncertainty rate and significant differences between countries in the same climate zone.

Considerable GHG emissions highlights significant potential role of organic soils in implementation of the climate change mitigation targets in LULUCF sector in the TCM climate zone; however, the analysis of LULUCF action plans and other national climate strategies do not reflects significant potential of the reduction of GHG emissions in areas with organic soils. The proposed measures usually have indirect impact, e.g. extensification of crop production and land use change from cropland to grassland or afforestation of cropland and grassland. In the most cases these measures do not have quantitative estimates in National reports on progress of implementation of LULUCF action plans according to EU decision 529/2013 Article 10 and National report on policies, measures and emission projections according to EU monitoring decision 525/2013 Article 13 and 14.

Multiple strategies for reduction of GHG emissions from organic soils are demonstrated in scientific literature, e.g. rewetting according to studies in Germany, afforestation and conversion of cropland to grassland according to results of LIFE REstore project and other studies, management of water regime in organic soils to avoid fluctuations of groundwater level.

The expert questionnaire based evaluation of the climate change mitigation measures applicable in organic soils demonstrates significant climate change mitigation potential, e.g. studies in Latvia demonstrates that nutrient-rich soils can be turned into net-sink of CO_2 removals without loosing of productivity using multiple strategies; however, there are significant knowledge gaps on the impact of these strategies on GHG emissions from soil. Another issue identified by the project is insufficient ability to monitor and to report the proposed measures, e.g. national land use parcel information systems (LPIS) are not ready to provide information necessary for accounting of GHG emissions from organic systems starting with basic information on area, moisture and nutritional regime of organic soils.

The study proves the significant climate change mitigation potential of organic soils in the TCM climate zone and highlights the demand for urgent research actions to ensure implementation and impact assessment of climate change mitigation actions in organic soils in the region.

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INTRODUCTION

Soil is the largest carbon pool in terrestrial ecosystems, one third to one-fifth of which comprises the carbon stock in organic soils (Lazdiņš & Lupiķis, 2019). According to the 2006 guidelines of The Intergovernmental Panel on Climate Change (hereinafter – IPCC) for National Greenhouse Gas (GHG) Inventories (hereinafter – 2006 IPCC guidelines, Eggleston, Buendia, Miwa, Ngara, & Kiyoto (2006)), soils are organic, if they meet the following criteria:

- thickness of the organic matter-rich layer is at least 10 cm, soil is never saturated with water or saturated only a few days per year, the content of organic carbon in a mixed 20 cm thick soil layer is at least 12%, but in the organic matter-rich layer the content of organic carbon is at least 20% (the content of organic matter is at least 35%);
- thickness of the organic matter-rich layer is at least 10 cm, soil is periodically or permanently saturated with water, in a mixed 20 cm thick soil layer the content of organic carbon is at least 12%, but in the organic matter-rich layer it is at least 12%, if soil does not contain clay particles (less than 0.002 mm in diameter) or at least 18%, if the content of clay particles in soil is 60% or the content of organic carbon corresponds with the regression line $f(x)=6.000x+6.000$, where $f(x)$ is threshold value for mass proportion of organic matter (%) and x is mass proportion of clay particles (%).

Organic soils have a large impact on the level of GHG emissions in the Land Use, Land-Use Change and Forestry (LULUCF) sector, including GHG emissions and CO_2 removals from the wetland, forest land, cropland, grassland and agricultural sector (Lazdiņš & Lupiķis, 2019).

Organic soils contribute to the atmospheric greenhouse gas (GHG) concentrations, as they can both remove and emit GHG, and have globally extensive carbon (C) and nitrogen (N) stores (Jauhiainen et al., 2019). Organic soils are, especially in the boreal region, commonly peat, derived from plant remains that have accumulated below the high water-table (WT) of peat-forming wetlands, peatlands. Below the WT decomposition is anaerobic and generally slow. Peatlands have been widely used for peat extraction or converted into agricultural and forestry land. These land uses typically involve drainage by ditching that is changing soil conditions radically. Draining of organic soils enhances aerobic decomposition and thus the mobilization of their C and N stores (Jauhiainen et al., 2019). Peat accumulation depends on the delicate balance between production and decay. The long-term carbon balance of natural peatlands is positive but carbon sequestration shows considerable year-to-year variability including short-term negative rates. In fact natural peatlands are rather close to the tipping point between carbon source and sink, making them sensitive to major climate change and human impact. Worldwide, undrained peatlands (>3 million km²) presently sequester up to 100 Megaton of carbon per year (Joosten, 2015). Decomposition of the dead plant material resulting in the emission of methane (CH_4). Natural peatlands are thus a major global source of CH_4. Methane is a much stronger greenhouse gas than CO_2 but has only a short atmospheric residence time (12 years, Joosten, 2015).

Drainage stops the emission of CH_4, but also results in emissions of CO_2 and the very strong greenhouse gas N_2O. These emissions continue as long as the peatland remains drained. In addition, large amounts of CH_4 are emitted from the drainage ditches, which also carry dissolved organic carbon (DOC) out of the peatland. The dissolved organic carbon is then largely decomposed off-site and emitted as CO_2. Emissions from peatlands generally increase with deeper drainage and warmer climates (Joosten, 2015).

Some 15% (650,000 km²) of the organic soils worldwide have been drained, mainly for cropland, grazing land, and forestry. This 0.4% of the global land area is responsible for some 5% of all global anthropogenic GHG emissions (Jauhiainen et al., 2019). In Europe, 48% of the organic soils are drained, especially in the temperate zone (Table 1).

Table 1: Total and drained organic soils in the world according to the Global Peatland Database 2015 (Concluding statement of the RRR2017 conference, 2017)

Continent	Organic soils		
	total, km²	drained, km²	drained, %
Asia	1500000	195000	13.0
Europe	594000	285000	48.0
Australasia	84000	15000	17.9
North America	1900000	23000	1.2
Africa	118000	12000	10.2
South America	157000	6300	4.0
Global	4353000	536300	14.0

The European Union is, after Indonesia, the second largest emitter of GHG from drained organic soils worldwide (The European Climate Initiative, 2010). Agriculture and forestry is an extensive land-use types on drained organic soils especially in northern Europe (Nordic and Baltic countries). The drained organic agricultural and forest soils of this region may act as significant sources of GHG, and the annual carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions and removals have to be reported in the national GHG inventories (Jauhiainen et al., 2019). As a high emission source organic soils also provide a large mitigation potential in a relatively small area, which is worth exploring in detail. Mitigation measures targeted to cultivated organic soils are often found to be the most efficient but the full mitigation potential is not utilized (Kekkonen et al., 2019).

The project consortium (Estonia, Finland, Germany, Latvia, Lithuania), totalling with 17 mill. ha of organic soils, represents 48% of organic soils in EU and 75% of organic soils in TCM climate zone, while the total area of the participating countries equals only to 25% of the EU area. The largest share of organic soils, both in the project consortium and in EU, is in Finland (38%). In other countries represented in the consortium share of organic is 15% in average, excluding Germany with only 2% of organic soils, but having considerable experience in development of paludicultures. It is 3rd to 5th largest proportion of organic soils in EU and Kyoto protocol Annex 1 countries. Annual carbon losses from managed organic soils in EU countries in 2016 corresponded to 106 mill. tons CO_2. Together with drainage and rewetting GHG emissions from organic soils in 2015 in EU was 117 mill. tons CO_2 eq. (3% of the net GHG emissions including LULUCF sector in EU). In the project region, GHG emissions from organic soils in 2015 was 32 mill. tons CO_2 eq. (27% form EU GHG emissions from organic soils and 40% of the net emissions including LULUCF sector in the participating countries). These figures prove that management of organic soils, especially nutrient-rich soils, should become the key priority in national climate policies, both in terms of improvement of accuracy of accounting of the emissions and implementation of the CCM measures. The project territory represents about 65% of the EU area and 45% of the organic soils in EU providing excellent opportunity to replicate project results outside the participating countries – in the whole TCM climate zone.

Summary of land uses in the project countries according to the most recent GHG inventory reports (NIR 2019) is provided in Table 2. Where information is not available it is assumed that all organic soils in cropland, grassland, settlements and forest land are nutrient-rich and in wetlands – nutrient-poor. The values in Table 2 are later used to estimate climate change mitigation effect. Considering that emissions from non-managed wetlands should not be reported in GHG inventories, the area of organic soils in wetlands may be underestimated. At the same time there are remarks in the inventories, e.g. in Latvia (Ministry of Environmental Protection and Regional Development, 2019a), area of organic soils in cropland and grassland may be overestimated.

Table 2: Organic soils in project partner countries

Indicator	Total	EE	DE	FI	LV	LT
Managed organic soils						
Ameliorated areas						
Nutrient rich soils						
Forest land	5055.05	157.70	114.88	4360.32	305.11	117.04
Cropland	815.93	23.80	383.34	261.02	78.63	69.14
Grassland	1222.63	11.74	1000.65	66.60	79.69	63.95
Settlements	108.73	0.96	78.48	17.91	9.10	2.28
Wetlands	-	-	-	-	-	-
Total nutrient rich soils	7202.34	194.20	1577.35	4705.85	472.53	252.41
Nutrient poor soils						
Forest land	252.63	105.70	-	-	89.51	57.42
Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
Wetlands	265.73	13.30	96.32	108.89	33.17	14.05
Total nutrient poor soils	518.35	119.00	96.32	108.89	122.68	71.47
Total managed nutrient rich ameliorated soils	7720.69	313.20	1673.66	4814.74	595.21	323.88
Naturally wet areas						
Nutrient rich soils						

Indicator	Total	EE	DE	FI	LV	LT
Forest land	2227.38	268.15	33.54	1603.68	149.81	172.20
Cropland	-	-	-	-	-	-
Grassland	111.29	31.91	73.65	0.00	0.00	5.73
Settlements	-	-	-	-	-	-
Wetlands	-	-	-	-	-	-
Total nutrient rich soils	2338.67	300.06	107.19	1603.68	149.81	177.93
Nutrient poor soils						
Forest land	193.74	-	-	-	193.74	-
Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
Wetlands	195.71	8.40	43.06	33.55	7.81	102.89
Total nutrient poor soils	389.45	8.40	43.06	33.55	201.55	102.89
Total managed nutrient poor naturally wet organic soils	2728.12	308.46	150.26	1637.23	351.36	280.82
All managed organic soils						
Nutrient rich soils						
Forest land	7282.43	425.85	148.43	5964.00	454.92	289.24
Cropland	815.93	23.80	383.34	261.02	78.63	69.14
Grassland	1333.92	43.65	1074.30	66.60	79.69	69.68
Settlements	108.73	0.96	78.48	17.91	9.10	2.28
Wetlands	-	-	-	-	-	-
Total nutrient rich soils	9541.01	494.26	1684.54	6309.53	622.34	430.34
Poor organic soils						
Forest land	446.37	105.70	-	-	283.25	57.42
Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
Wetlands	461.44	21.70	139.38	142.44	40.98	116.94
Total nutrient poor soils	907.80	127.40	139.38	142.44	324.23	174.36
Total managed organic soils	10448.82	621.66	1823.92	6451.97	946.57	604.70
Non-managed lands						
Ameliorated areas						
Nutrient rich soils						
Forest land	-	-	-	-	-	-
Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
Wetlands	-	-	-	-	-	-
Total nutrient poor soils	-	-	-	-	-	-
Nutrient poor soils						

Indicator	Total	EE	DE	FI	LV	LT
Forest land	-	-	-	-	-	-
Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
Wetlands	-	-	-	-	-	-
Total nutrient poor soils	-	-	-	-	-	-
Total non-managed nutrient rich ameliorated soils	-	-	-	-	-	-
Naturally wet areas						
Nutrient rich soils						
Forest land	-	-	-	-	-	-
Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
Wetlands	28.80	-	-	-	28.80	-
Total nutrient poor soils	28.80	-	-	-	28.80	-
Nutrient poor soils						
Forest land	-	-	-	-	-	-
Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
Wetlands	7052.58	391.33	-	6297.94	129.17	234.14
Total nutrient poor soils	7052.58	391.33	-	6297.94	129.17	234.14
Total non-managed nutrient poor naturally wet organic soils	7081.38	391.33	-	6297.94	157.97	234.14
All managed organic soils						
Nutrient rich soils						
Forest land	-	-	-	-	-	-
Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
Wetlands	28.80	-	-	-	28.80	-
Total nutrient poor soils	28.80	-	-	-	28.80	-
Poor organic soils						
Forest land	-	-	-	-	-	-
Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
Wetlands	7052.58	391.33	-	6297.94	129.17	234.14
Total nutrient poor soils	7052.58	391.33	-	6297.94	129.17	234.14
Total non-managed organic soils	7081.38	391.33	-	6297.94	157.97	234.14

Indicator	Total	EE	DE	FI	LV	LT
All organic soils (managed and non-managed)						
Ameliorated areas						
Nutrient rich soils						
Forest land	5055.05	157.70	114.88	4360.32	305.11	117.04
Cropland	815.93	23.80	383.34	261.02	78.63	69.14
Grassland	1222.63	11.74	1000.65	66.60	79.69	63.95
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Nutrient poor soils						
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Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
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Naturally wet areas						
Nutrient rich soils						
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Grassland	111.29	31.91	73.65	-	-	5.73
Settlements	-	-	-	-	-	-
Wetlands	28.80	-	-	-	28.80	-
Total nutrient poor soils	2367.47	300.06	107.19	1603.68	178.61	177.93
Nutrient poor soils						
Forest land	193.74	-	-	-	193.74	-
Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
Wetlands	7248.29	399.73	43.06	6331.49	136.98	337.03
Total nutrient poor soils	7442.03	399.73	43.06	6331.49	330.72	337.03
Total nutrient poor naturally wet organic soils	9809.50	699.79	150.26	7935.17	509.33	514.96
All organic soils						
Nutrient rich soils						
Forest land	7282.43	425.85	148.43	5964.00	454.92	289.24
Cropland	815.93	23.80	383.34	261.02	78.63	69.14
Grassland	1333.92	43.65	1074.30	66.60	79.69	69.68
Settlements	108.73	0.96	78.48	17.91	9.10	2.28
Wetlands	28.80	-	-	-	28.80	-
Total nutrient poor soils	9569.81	494.26	1684.54	6309.53	651.14	430.34

Indicator	Total	EE	DE	FI	LV	LT
Poor organic soils						
Forest land	446.37	105.70	-	-	283.25	57.42
Cropland	-	-	-	-	-	-
Grassland	-	-	-	-	-	-
Settlements	-	-	-	-	-	-
Wetlands	7514.02	413.03	139.38	6440.38	170.15	351.08
Total nutrient poor soils	7960.38	518.73	139.38	6440.38	453.40	408.50
Total organic soils	17530.20	1012.99	1823.92	12749.91	1104.54	838.84

The most of the organic soils according to GHG inventories are located in forest lands and wetlands (Figure 1). Nutrient rich forest soils are 55% of the total area of organic soils. Considerably bigger share of nutrient rich organic soils is reported in Germany.

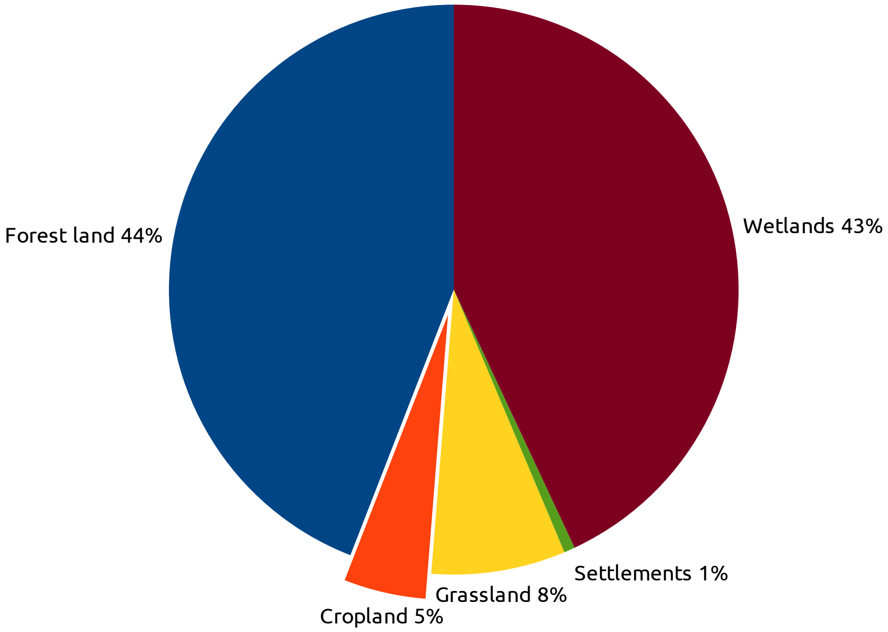

Figure 1: Distribution of organic soils in participating countries.

As a high emission source organic soils also provide a large mitigation potential in a relatively small area, which is worth exploring in detail. Land management, in general, play a central role in climate change mitigation in the EU. There is an extensive list of potential measures that can be taken in land management for mitigating emissions and which are technically feasible. Mitigation measures targeted to cultivated organic soils are often found to be the most efficient but the full mitigation potential is not utilized (Kekkonen et al., 2019).

1. CURRENT MANAGEMENT PRACTICES OF NUTRIENT RICH ORGANIC SOILS IN BOREAL AND TEMPERATE COOL MOIST CLIMATE ZONE IN EUROPE

European soils store around 73 to 79 billion tonnes of carbon (Gobin et al., 2011). The largest organic carbon (OC) contents were observed in Ireland, the United Kingdom, Sweden, Finland, Estonia and Latvia, mostly in wetlands (peat lands), woodlands and in mountainous areas (Figure 2 de Brogniez et al., 2014). Particularly important are peatland soils, as they store 17 billion tonnes of carbon (around 20-25% of the total), whilst covering only 31 Mha or 7% of the EU-27 surface area. Peatlands are mainly located in Scandinavia, Ireland, northern Britain and Germany. Soils are an important carbon stock: more than twice as much carbon is held in soils as compared to vegetation or the atmosphere. Soil organic carbon (SOC) stocks are dynamic and changes in land use, land management and climate all have significant impacts. Both the European Commission and the United Nation’s IPCC identify the decline of SOC worldwide as an environmental risk that undermines not only soil fertility and productivity, and hence food security, but also the progressive stabilisation and subsequent reduction of atmospheric CO_2 concentration levels. Soil organic matter monitoring programmes, long term experiments and modelling studies all indicate that changes in land use significantly affect soil organic matter levels. Soil organic matter losses occur when grasslands, forests and natural vegetation are converted to cropland. The reverse is true if croplands are converted to grasslands, forests and natural vegetation. Land use changes can result in rapid carbon losses (i.e. instant), whereas gains accumulate more slowly (i.e. decadal, Gobin et al., 2011).

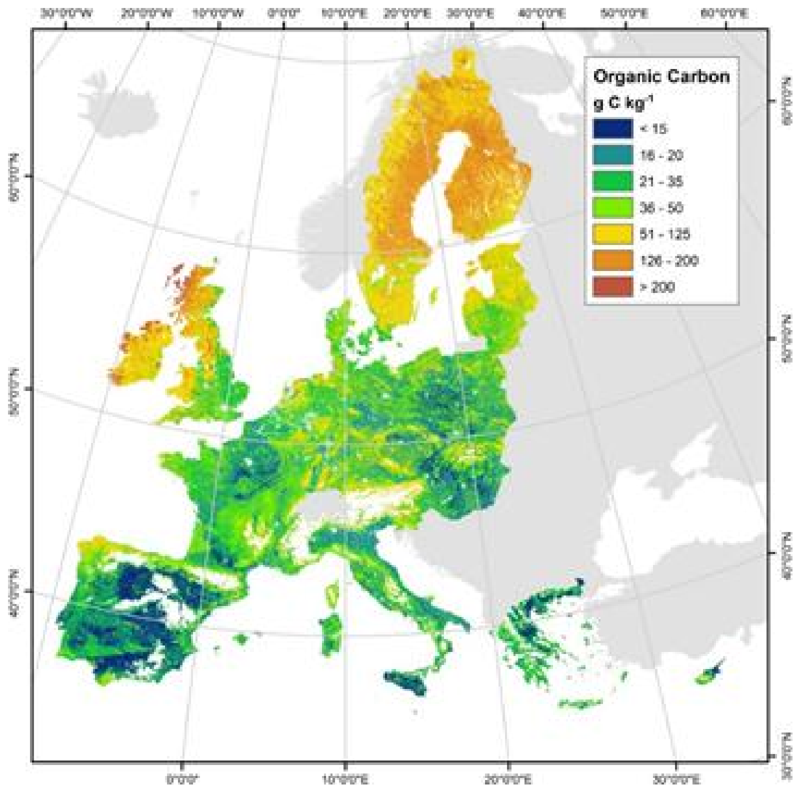

Figure 2: Map of topsoil organic carbon content (g C kg^{-1}, de Brogniez et al., 2014).

In the EU Member States, for cropland and grassland the emissions from organic soils are the main emission source. Based on the reported GHG emissions (NIR, 2017) the total emissions from organic soils under cropland (CRF Table 4B) amount 31 mill. tons CO_2 in 2015 (18.3 ton CO_2 ha^{-1} $year^{-1}$) and under grassland (CRF Table 4C) 38 mill. tons CO_2 (16 ton CO_2 ha^{-1} $year^{-1}$). These emissions are mainly occurring in Member States with large peat areas, which are located in North and Northwest Europe (Figure 3, Paquel et al., 2017).

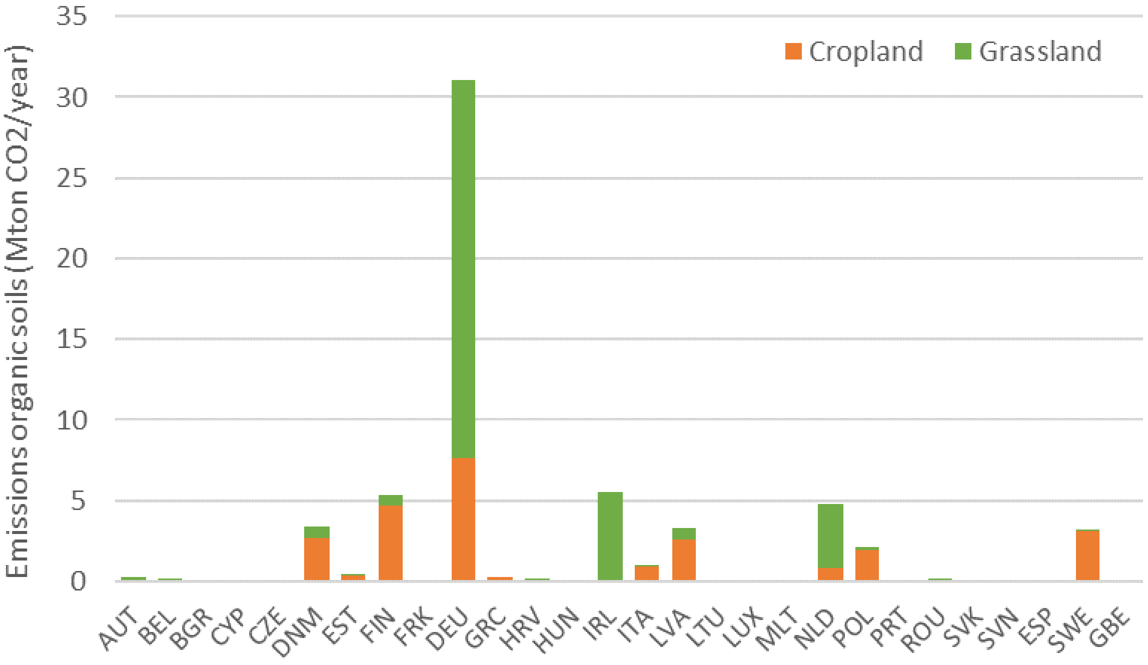

Figure 3: Emissions from organic soils under cropland (only cropland remaining cropland) and grassland (only grassland remaining grassland) per EU Member State in 2015 (Paquel et al., 2017).

The Common Agricultural Policy (CAP), and particularly its Rural Development programmes, are key to the EU Member States’ climate action in LULUCF sector. The LULUCF actions stem also from the national forestry policies, shaped in part to reflect the concept of sustainable forest management. The role of multi-functional forests is often raised by the Member States as a way of seeing forests as providers of goods and services, including biomass for energy and other commercial uses, and climate mitigation. Forest management is the most frequently reported LULUCF activity covering a broad range of actions, including many designed to enhance forest productivity and resilience to fires. A bulk of sustainable forest management practices and actions are supported under the CAP. Additional EU policy instruments reported by the Member States as encouraging the LULUCF actions include: the LIFE programme, the Natura 2000 legislation, the Nitrates Directive, the INSPIRE Directive, and the Renewable Energy Directive. Only a few policy tools designed at national level were identified, including among others fiscal instruments to encourage a higher biomass uptake (Paquel et al., 2017).

The most frequently reported areas of intervention by EU Member States (including LIFE OrgBalt countries) that directly or indirectly attributes to the management of organic soils are (Paquel et al., 2017):

- forest management;
- protection against natural disturbances;
- afforestation and reforestation;

- biodiversity/nature conservation measures;
- biomass for energy use;
- grassland, grazing land and/or pasture management;
- nutrient, tillage and water management;
- conservation of carbon in existing forests;
- restoration of degraded land;
- organic farming;
- substitution of GHG intensive materials with harvested wood products (HWP);
- avoided deforestation.

A range of climate change mitigation measures directly related to the management of organic soils (reported by the EU Member States) include (Paquel et al., 2017):

- conversion of arable land on organic soils to nature (natural habitat) or to grassland and pasture;
- converting cropland from annual tillage crops to perennial crops;
- use of submerged drains and raising water levels for grassland areas with deep drainage;
- afforestation of organic soil;
- rewetting of organic soils;
- rehabilitation of moorland and restoration of wetlands, protection of bogs;
- initiatives to limit consumption of peat in horticulture;
- protection and management of the Natura 2000 network;
- pasture suitable for carbon storage.

1.1 Regional extent in Boreal and Temperate Cool Moist climate zone

According Party GHG Inventory Submissions 2019 the most common land use type on organic soil in boreal and temperate cool moist climate zones in Europe is wetlands (about 50% of the total area of organic soil), including peat extraction areas (about 0.7% of the total area of organic soil) and flooded wetlands (about 1.1% of the total area of organic soil). About 35% of the total area of organic soils is managed as forest land, about 10% is managed as grassland and only around 5% is managed as croplands (Figure 4, 5 and 6).

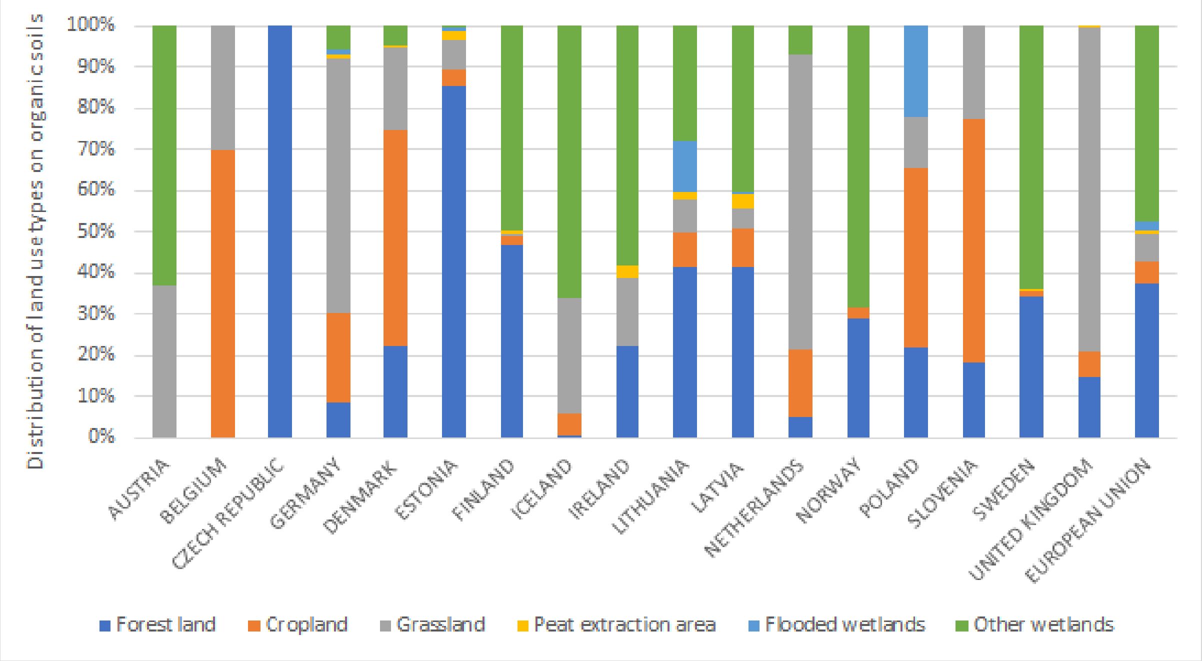

Figure 4: Distribution of land use types on organic soils in countries in Boreal and Temperate Cool Moist climate zones in Europe in 2017 (according Party GHG Inventory Submissions 2019).

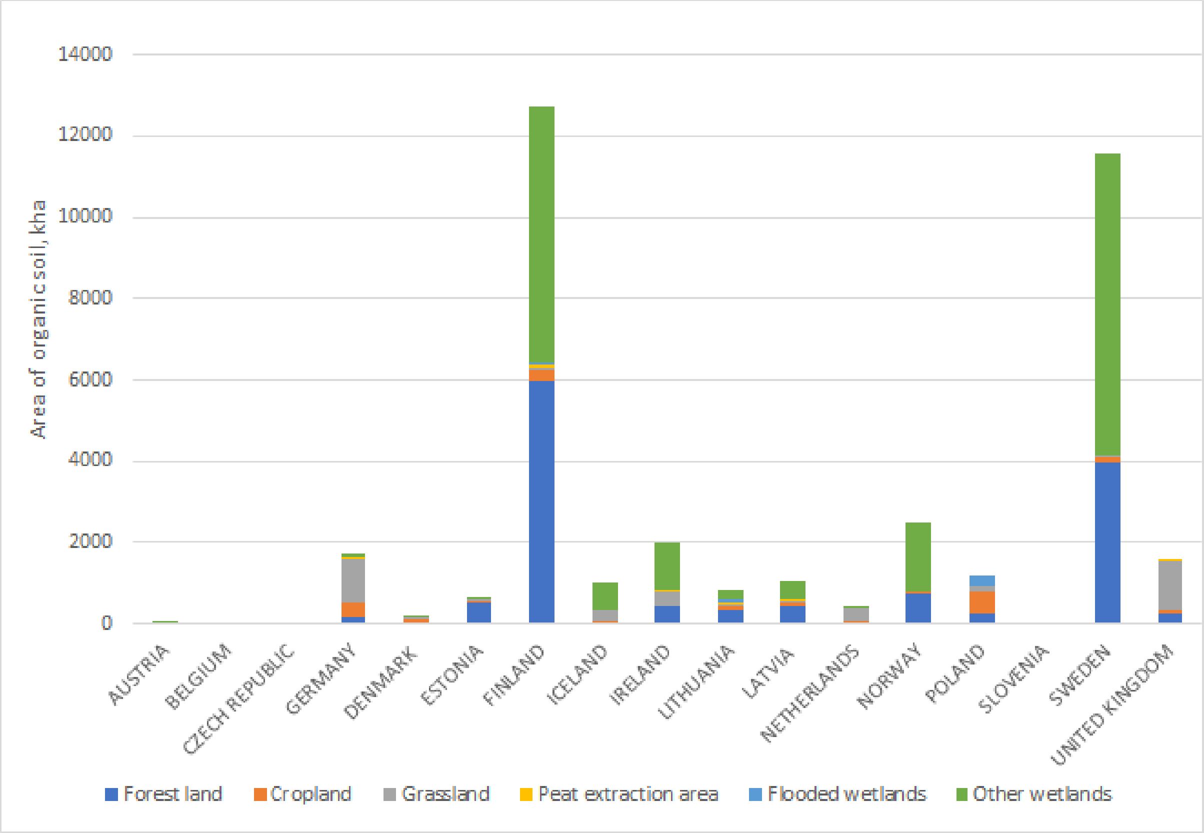

Figure 5: Area of organic soil by land use types in countries in Boreal and Temperate Cool Moist climate zones in Europe in 2017 (according Party GHG Inventory Submissions 2019).

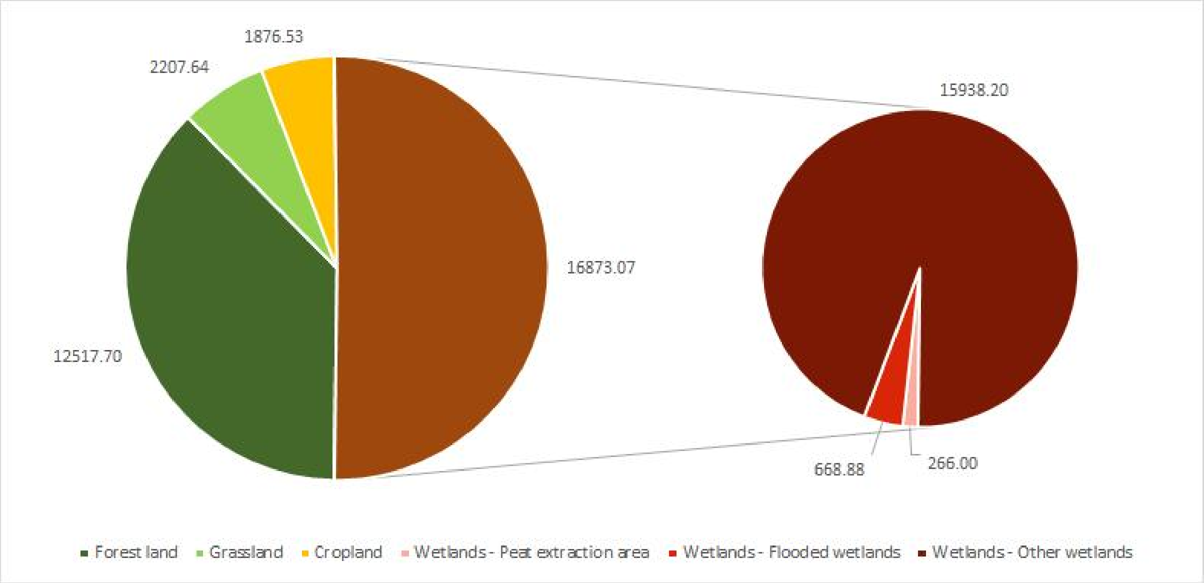

Figure 6: Total area (kha) of organic soil by land use types in European Union in 2017 (according Party GHG Inventory Submissions 2019).

1.2 Regional extent in Boreal and Temperate Cool Moist climate zone

The total area of organic soils in EU is 34.5 mill. ha (7% of EU area). The project is targeted on the most common group of managed organic soils in EU – nutrient-rich drained soils in cool & temperate cool & moist (TCM) climate zone, totalling about 21 mill. ha (according to Harmonised World Soil Database v 1.2) or 61% of organic soils in EU. Please refer to the Map of IPCC climate zones (according to Eggleston et al., 2006) in Figure 7.

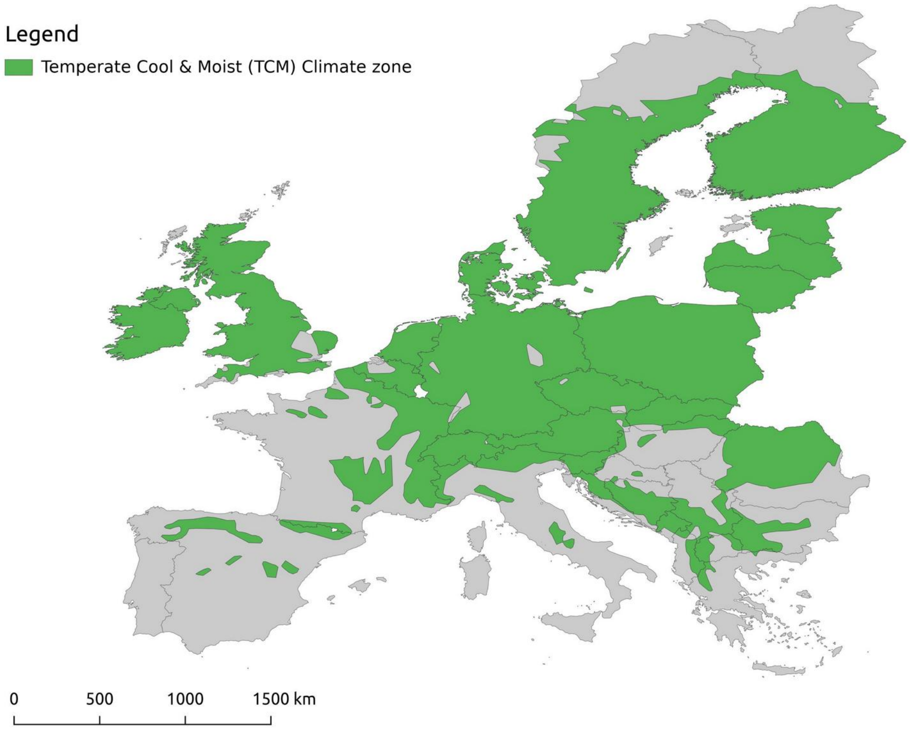

Figure 7: Temperate cool and moist (TCM) climate zone.

1.3 Management practices in LIFE OrgBalt countries

In LIFE OrgBalt countries, in total 43.7% of organic soils are occupied by forest land, 41.7% - by wetlands (excluding peat extraction areas and flooded wetlands), 7.7% - by grassland, 4.9% - by cropland, 1.1% - by peat extraction area and 0.9% by flooded wetlands (according to the IPCC (Intergovernmental Panel on Climate Change) land use definitions; GHG Inventory Submissions 2019).

The most appropriate measures for LIFE OrgBalt countries that are planned or are to be implemented, taking into account national circumstances, in order to pursue the mitigation potential, are described in the following paragraphs.

1.3.1 Estonia

In Estonia, 85.6% of total organic soils are occupied by forest land, 7.0% - by grasslands, 3.8% - by cropland, 2.1% - by peat extraction areas, 1.0% - flooded wetlands and 0.4% by other wetlands (according to the IPCC (Intergovernmental Panel on Climate Change) land use definitions; GHG Inventory Submissions 2019).

Emission factors used to calculate carbon stock changes in organic soils in different land use types within National GHG Inventory 2019 are summarized in Table 3. The biggest net carbon stock change in soils per area (-15.63 t C ha^{-1}) is indicated for peat extraction areas.

Table 3: Emission factors used to calculate carbon stock changes in organic soils in different land use types in Estonia (National GHG Inventory 2019)

Land use		Net carbon stock change in soils per area, t C ha^{-1}
Category	**Sub-category**	
Forest land	Forest land remaining forest land	-0.16
	Land converted to forest land (average)	-0.34
	Cropland converted to forest land	NO
	Grassland converted to forest land	-0.34
	Wetlands converted to forest land	-0.34
	Settlements converted to forest land	-0.34
	Other land converted to forest land	NO
Cropland	Cropland remaining cropland	-6.10
	Land converted to cropland (average)	-6.10
	Forest land converted to cropland	NO
	Grassland converted to cropland	-6.10
	Wetlands converted to cropland	-6.10
	Settlements converted to cropland	NO
	Other land converted to cropland	NO
Grassland	Grassland remaining grassland	-0.33
	Land converted to grassland (average)	-4.98
	Forest land converted to grassland	-1.35
	Cropland converted to grassland	-6.10
	Wetlands converted to grassland	-1.35
	Settlements converted to grassland	NO
	Other Land converted to grassland	NO
Wetlands	Wetlands remaining wetlands (average)	-10.60
	Peat extraction remaining peat extraction	-15.63
	Flooded land remaining flooded land	NA
	Other wetlands remaining other wetlands	NO
	Land converted to wetlands (average)	-0.20
	Land converted to peat extraction	-1.74
	Land converted to flooded land	NA

Land use		Net carbon stock change in soils per area, t C ha^{-1}
Category	**Sub-category**	
	Land converted to other wetlands	NA
Settlements	Settlements remaining settlements	NO
	Land converted to settlements (average)	-2.09
	Forest land converted to settlements	-1.62
	Cropland converted to settlements	-6.10
	Grassland converted to settlements	NO
	Wetlands converted to settlements	NO
	Other Land converted to settlements	NO
Other land	Other land	NO

Emission factors for calculation of emissions and removals from drainage and rewetting and other management of organic soils for forest land and wetlands in Estonia are summarized in Table 4. Emissions from drained or rewetted organic soils in cropland and grassland within National GHG Inventory 2019 are not reported.

Table 4: Emission factors for calculation of emissions from drainage and rewetting and other management of organic soils in Estonia

Land use	Type of soil	Emission factors		
		CO_2, kg CO_2 ha^{-1}	N_2O-N, kg N_2O-N ha^{-1}	CH_4, kg CH_4 ha^{-1}
Forest land	Drained organic soils	IE	2.00	9.33
Wetlands, Peat extraction lands	Drained organic soils	IE	0.19	0.16

Climate change mitigation targeted measures (LULUCF actions) applied to managed organic soils (mostly indirectly, meaning – although measures are not directly attributed to the management of organic soils, impact persists) are reported by Estonia under Article 10 of the LULUCF Decision (LULUCF Actions Plans, initial and progress reports submitted between 2014 and 2018) 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 (MMR_PAMs, 2017) are summarized in Table 5.

Table 5: LULUCF actions applied to organic soil management in Estonia

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
Cropland management			
Cropland	Support for growing plants of local varieties	The measure helps to preserve crop varieties more suitable for local conditions (more resistant to locally spread diseases and climate conditions) and therefore gives a good basis for developing new breeds and supports organic farming. The objective of this measure is to ensure the preservation of the local crop varieties and domestic animal breeds valuable for cultural heritage and genetic diversity.	2014-2020, Rural Development Programme 2014-2020
Cropland	Support for environmentally friendly management	The objectives of the support for environmentally friendly management are the following: to promote the introduction and continual use of environmentally friendly management methods in agriculture, in order to protect and increase	2014-2020, Rural Development Programme 2014-2020

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
		biological and landscape diversity and to protect the status of water and soil; to expand environmentally friendly planning in agriculture; to increase the awareness of agricultural producers of the environment.	
Cropland	Support for the establishment of protection forest on agricultural land	With the establishment of protection forests, the share of agricultural lands sensitive to the environment will be reduced and the need to establish protection forests on the account of commercial forests will be decreased. With the establishment of small groves forest, the biodiversity will be increased in particular areas as well. The measure supports the permanent conversion of vulnerable agricultural lands to protected forest lands. The support prevents land use change from nature and habitat conservation to intensive farming.	2014-2020, Rural Development Plan 2007-2013
Cropland	Organic farming	The objectives of the support for organic farming are the following: to support and improve the competitiveness of organic farming; to maintain and increase biological and landscape diversity; to maintain and improve soil fertility and water quality; to improve animal welfare. Mitigation effect: GHG (CO_2, N_2O, CH_4) emissions reduction.	2014-2020, Rural Development Programme 2014-2020
Cropland	Support for environmentally friendly horticulture	The overall objective of the support for environmentally friendly horticulture is to implement environmentally friendly practices in growing horticultural crops. The specific goals are the following: to decrease the use of pesticides; to grant healthier food supply for consumers; to decrease nutrient leaching in the soil; to support the maintenance of biological diversity in agricultural landscapes. Supported are environmentally friendly fruit and berry growing, vegetable, medicinal and aromatic plant cultivation and strawberry growing. Mitigation effect: GHG (CO_2, N_2O) emissions reduction	2014-2020, Rural Development Programme 2014-2020
Cropland	Crop diversification	The objective of the measure is to make farms with monocultures more environmentally friendly and sustainable. A farmer must cultivate at least two crops when his arable land exceeds 10 hectares and at least three crops when his arable land exceeds 30 hectares. The main crop may cover at most 75% of arable land, and the two main crops at most 95% of the arable area. Mitigation effect: GHG (CO_2, N_2O) emissions reduction, carbon sequestration.	2014-2020, Common Agricultural Policy (EU)
Cropland	Ecological focus area protection	The overall objectives of ecological focus area protection measure is to safeguard and improve biodiversity on farms. The support is granted through direct payments (DP) to farmers. At least 5% of the arable land area of the holding must be maintained as an ecological focus area for farms with an area larger than 15 hectares (excluding permanent grassland) – i.e. field margins, hedges, trees, fallow land, landscape features, biotopes, buffer strips, afforested area. Mitigation effect: GHG (CO_2, N_2O) emissions reduction, carbon sequestration.	Common Agricultural Policy (EU)
Grazing land management and pasture improvement			
Agri-cultural land	Support for the maintenance of semi-natural habitats	The overall objectives of this measure are: to improve the quality of maintenance of semi-natural habitats whereas increasing the share of semi-natural habitats maintained by farm animals, to preserve and increase biological and landscape diversity; to increase the area of land under maintenance; to improve the condition of species related to	2014-2020, Rural Development Programme 2014-2020

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
		semi-natural habitats. Mitigation effect: GHG (CO_2, N_2O) emissions reduction	
Agricultural land	Natura 2000 support for agricultural land	The overall objective of Natura 2000 support for agricultural land is to ensure conformity with nature protection requirements in Natura 2000 network areas, to maintain agricultural activity in those areas and to contribute to coping with handicaps, resulting from the implementation of Council Directive 79/409/EEC on the conservation of wild birds and Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, in order to ensure the efficient management of Natura 2000 areas. The support prevents land use change from nature and habitat conservation to intensive farming. Mitigation effect: GHG (CO_2, N_2O) emissions reduction.	Rural Development Programme 2014-2020
Grassland	Preservation of permanent grassland	The objective of the measure is to avoid massive conversion of grassland to arable land. The member state is obliged to maintain the total area of permanent grassland. Estonia has to maintain the area of permanent grassland at least on the level of the year 2005. Mitigation effect: GHG (CO_2, N_2O) emissions reduction, carbon sequestration. Policy: Commission Regulation (EC) No 73/2009. Good Agricultural and Environmental Conditions, Detailed Procedure for the Fulfilment of the Commitment to Maintain Permanent Pasture, Bases and Procedure for the Transfer of the Commitment to Maintain Permanent Pasture and Detailed Procedure for the Application of the Measures Necessary for the Maintenance of Permanent Pasture.	See previous column "Objectives and short description"
Agricultural land	Support for advisory systems and services	The overall objective of the measure is to help people involved in agriculture to manage their household or company sustainably or increase profitability through quality advisory service. More specific objectives are: To grant advisory services in the sectors most important for the state and more active use of professional advice; To developing nation-wide integrated advisory system; To train advisors, to ensure their relevant and up to date knowledge and to improve the quality of advisory systems. Mitigation effect: GHG (CO_2, N_2O, CH_4) emissions reduction, carbon sequestration.	Rural Development Programme 2014-2020
Management of agricultural organic soils, in particular, peat lands			
Agricultural land	Regional support for soil protection	The aims of the measure are to: limit GHG emissions, limit soil erosion, reduce nutrient leaching and maintain and raise the content of soil organic matter. Mitigation effect: GHG (CO_2, N_2O) emissions reduction.	2014-2020, Rural Development Programme 2014-2020
Measures to prevent drainage and to incentivise rewetting of wetlands & measures related to existing or partly drained mires			
Wetlands	Mitigating the negative impacts of climate change on biological diversity	The objective of the measures is to ascertain the impact of climate change on biodiversity through monitoring particular sensitive habitat types and populations of species, analysing the trends and developing and applying mitigation measures, such as ecologically coherent green infrastructure buffering environmental changes, conservation and restoration of mires and forests, which remove carbon from the global cycle, and maintenance of semi-natural communities. Pursuant to the Global Biodiversity Strategy, human impact on sensitive ecosystems affected by climate change is to be minimised, maintaining their integrity and functioning.	Estonian Nature Conservation Development Plan until 2020

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
		Mitigation effect: GHG (CO_2, CH_4) emissions reduction.	
Wetlands	Ensuring the favourable conservation status of habitats	The objective of the measure is to improve the conservation status of at least 14 habitat types in Estonia due to the applied protection measures. The immediate outcome of the activity of the measure is 10 000 ha of fen and transition mire habitats and raised bog margins (lag-zones, mixotrophic and ombrotrophic forests, degraded raised bogs still capable of natural regeneration) in protected areas. Mitigation effect: GHG (CO_2, CH_4) emissions reduction, carbon sequestration	Estonian Nature Conservation Development Plan until 2020
Restoration of degraded lands			
Degraded lands	Restoration of the land degraded by extraction	The objective of the measure is to adjust the land degraded by extraction to forest land, water body, land with recognized value or to any other kind of land that can be used for beneficial purposes. After the peat has issued and degraded land arranged there will be no GHG emissions related to peat decomposition and therefore the measures is beneficial in terms of GHG emissions reduction. Mitigation effect: GHG (CO_2, CH_4) emissions reduction.	Earth's Crust Act
Wetlands	Restoration of contaminated sites and water bodies, activity: Restoration of exhausted and abandoned peatlands and drained peatlands	The overall objective of the measure is to grant the restoration of the sites, water bodies and wetlands that pose a threat to living and natural environment. There are 2000 ha of exhausted and abandoned peat extraction sites from Soviet times that are sources of GHG emissions due to the removed vegetation layer. The objective of the measure is to restore the water regime of the 2000 ha abandoned peat extraction sites in order to allow re-creation of bogs or afforestation. Mitigation effect: GHG (CO_2, CH_4) emissions reduction.	EU Cohesion Fund
Measures related to forestry activities			
Forest land	Promotion of regeneration of forests in managed private forests with the tree species suitable for the habitat type.	The measure grants the supply of tree species suitable for the habitat type to promote efficient and fast regeneration of private forests. The measure has a positive effect on the growth of a new forest which helps to reduce GHG emissions and increase carbon uptake from felling areas. Mitigation effect: GHG (CO_2) emissions reduction, carbon sequestration	2011-2020, Estonian Forestry Development Programme until 2020
Forest land	Reforestation	The objective of the measure is to support regeneration of forest after felling or natural disturbances. According to Forest Act, the forest owner is obliged to assure regeneration of forest no later than 5 years after felling or natural disturbances. Mitigation effect: GHG (CO_2) emissions reduction, carbon sequestration.	Forest Act
Forest land	Increasing forest increment and ability to sequestrate carbon through timely regeneration of forests for climate change mitigation	The overall objective is to support activities related to timely regeneration of forests in order to mitigate climate change. The measure helps to increase GHG removals and decrease emissions by/from forest land. Mitigation effect: GHG (CO_2) emissions reduction, carbon sequestration.	2011-2020, Estonian Forestry Development Programme until 2020
Forest land	Natura 2000 support for private forest land (Maintaining biological processes and preserving population of species that are	The overall objective of the measure is to maintain biological and landscape diversity in Natura 2000 areas covered with forests. Protected areas, special conservation areas and species protection sites on forest land will help to preserve forest carbon stock from those areas. Mitigation effect: GHG (CO_2) emissions reduction, carbon sequestration.	Rural Development Programme 2014-2020

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
	common to Estonia)		
Forest land	Development and maintenance of infrastructure for agriculture and forest management	The overall objective of the measure is to balance production conditions of agriculture and private forest management in various rural areas by reducing the risks caused by unfavourable water regime and increasing the productivity of private forests. Also, to improve access to agricultural land and private forest land. Mitigation effect: GHG (CO_2) emissions reduction, carbon sequestration.	Rural Development Programme 2014-2020
Forest land	Improvement of forest economic and ecological vitality	The overall objective of supporting forestry as an integral part of rural life, is sustainable and effective forest management which promotes raising vitality of forests by improving its species composition or implementing other silvicultural techniques, maintaining and renewing forest biological diversity, integral ecosystem and protection function by helping to preserve forest's multifunctional role and its spiritual and cultural heritage. Mitigation effect: GHG (CO_2) emissions reduction, carbon sequestration.	2014-2020, Rural Development Programme 2014-2020
Strengthening protection against natural disturbances such as fire, pests, and storms			
Forest land	Improving forest health condition and preventing the spreading of dangerous forest detractors.	The measure provides support for monitoring and restoration of forests in order to improve forest health condition and prevent damage caused by fire, pests and storms. The measure is aimed to increase removals of GHG by Estonian forests due to their better health condition. Mitigation effect: GHG (CO_2) emissions reduction, carbon sequestration.	2011-2020, Estonian Forestry Development Programme until 2020
Forest land	Obligations of owner in forest management	The objective of the measure is to grant that forest health condition is continuously observed and the forest is protected against disturbances. According to Forest Act, the forest owner is obliged to observe forest condition and protect it against pests, diseases and forest fires. Mitigation effect: GHG (CO_2) emissions reduction, carbon sequestration.	Forest Act

1.3.2 Finland

In Finland, 49.6% of total organic soils are occupied by wetlands (excluding peat extraction areas and flooded wetlands), 46.8% - by forest land, 2.1% - by cropland, 0.9% - by peat extraction area, 0.5% by grassland and 0.1% - by flooded wetlands (according to the IPCC (Intergovernmental Panel on Climate Change) land use definitions; GHG Inventory Submissions 2019).

Emission factors used to calculate carbon stock changes in organic soils in different land use types within National GHG Inventory 2019 are summarized in Table 6. The biggest net carbon stock change in organic soils per area (-6.80 t C ha^{-1}) is indicated for land converted to cropland.

Table 6: Emission factors used to calculate carbon stock changes in organic soils in different land use types in Finland (National GHG Inventory 2019)

Land use		Net carbon stock change in organic soils per area, t C ha^{-1}
Category	Sub-category	
Forest land	Forest land remaining forest land	-0.19
	Land converted to forest land (average)	-1.55

Land use		Net carbon stock change in organic soils per area, t C ha^{-1}
Category	**Sub-category**	
	Cropland converted to forest land	-4.81
	Grassland converted to forest land	-1.82
	Wetlands converted to forest land (average)	-0.78
	Wetlands (peat extraction) converted to forest land	-1.30
	Wetlands (drained wetlands) converted to forest land	-0.65
	Settlements converted to forest land	-0.74
	Other land converted to forest land	NA
Cropland	Cropland remaining cropland	-6.59
	Land converted to cropland (average)	-6.80
	Forest land converted to cropland	-6.80
	Grassland converted to cropland	-6.80
	Wetlands converted to cropland	-6.80
	Settlements converted to cropland	NA
	Other land converted to cropland	NA
Grassland	Grassland remaining grassland	-3.50
	Land converted to grassland (average)	-3.50
	Forest land converted to grassland	-3.50
	Cropland converted to grassland	-3.50
	Wetlands converted to grassland	-3.50
	Settlements converted to grassland	NA
	Other Land converted to grassland	NA
Wetlands	Wetlands remaining wetlands (average)	-0.07
	Peat extraction remaining peat extraction (average)	-3.97
	Peat extraction remaining peat extraction	-3.98
	Peat extraction from wetlands	-3.93
	Flooded land remaining flooded land (average)	-0.08
	Inland waters from wetlands	-0.40
	Inland waters managed	NA
	Other wetlands remaining other wetlands (average)	-0.01
	Inland waters remaining inland waters	NA
	Other WL from Peat Extraction	-2.38
	Other WL managed	-1.77
	Other WL remaining Other WL	NA
	Land converted to wetlands (average)	-2.00
	Land converted to peat extraction (average)	-3.93
	Grassland	NA
	Forest land	-3.93
	Cropland	-3.89
	Land converted to flooded land (average)	-0.14

Land use		Net carbon stock change in organic soils per area, t C ha^{-1}
Category	**Sub-category**	
	Forest land converted to flooded land	-0.27
	Cropland converted to flooded land	NA
	Grassland converted to flooded land	NA
	Settlements converted to flooded land	-0.12
	Other land converted to flooded land	NA
	Land converted to other wetlands (average)	-1.66
	Forest land converted to other wetlands	-1.84
	Grassland converted to other wetlands	NA
	Settlements converted to other wetlands	NA
Settlements	Settlements remaining settlements	NA
	Land converted to settlements	NA
Other land	Other land	NO

Emission factors for calculation of emissions and removals from drainage and rewetting and other management of organic soils for forest land and wetlands in Finland are summarized in Table 7. Emissions from drained or rewetted organic soils in cropland and grassland within National GHG Inventory 2019 are not reported.

Table 7: Emission factors for calculation of emissions from drainage and rewetting and other management of organic soils in Finland

Land use	Type of soil	Emission factors		
		CO_2, kg CO_2 ha^{-1}	N_2O-N, kg N_2O-N ha^{-1}	CH_4, kg CH_4 ha^{-1}
Forest land	Drained organic soils	IE	0.95	7.75
Wetlands, Peat extraction lands	Drained organic soils	IE	1.84	22.79
Wetlands, Flooded lands	Other organic soils	IE	NA	15.47

Climate change mitigation targeted measures (LULUCF actions) applied to managed organic soils (mostly indirectly, meaning - although measures are not directly attributed to the management of organic soils, impact persists) are reported by Finland under Article 10 of the LULUCF Decision (LULUCF Actions Plans, initial and progress reports submitted between 2014 and 2018) 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 (MMR_PAMs, 2017) are summarized in Table 8.

Table 8: LULUCF actions applied to organic soils management in Finland

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
Forest land	National Forest Strategy 2025	The vision of the NFS is "Sustainable forest management is a source of growing welfare". The three strategic objectives of the NFS are: 1) Finland is a competitive operating environment for forest based business, 2) Forest-based business and activities and	2015-2025, National Forest Strategy 2025

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
		their structures are renewed and diversified and 3) Forests are in active, economically, ecologically and socially sustainable,and diverse use. According to the NFS, climate change mitigation and adaptation in forestry are supported by diverse management and use of forest resources. The long-term goal is to adapt forest management practices to meet changing climate conditions.	
Forest land	National Forest Strategy 2025: Forest-related information and e-services of the future.	The project will develop a next-generation forest related information system and a process for keeping the information resources up to date.	2015-2025, National Forest Strategy 2025
Forest land	National Forest Strategy 2025: Statistics on the renewing forest-based business and activities.	Collection of statistics on the interfaces between the forest, energy and chemical industries, nature tourism, forestry-related services and other forest-based business and ecosystem services will be improved.	2015-2025, National Forest Strategy 2025
Forest land	National Forest Strategy 2025: Development of active forest management, entry of timber to the market and forest ownership structure.	Underpinned by studies, forestry taxation and legislation will be developed to support active forest management, entry of timber to the market and a change in the forest ownership structure.	2015-2025, National Forest Strategy 2025
Forest land	National Forest Strategy 2025: New incentive schemes and resource-efficient forest management.	The project will prepare a future incentive scheme for forest management that promotes active and resource efficient forest use and welfare derived from non-market benefits.	2015-2025, National Forest Strategy 2025
Agri-cultural land	Climate Programme for Finnish Agriculture – Steps Towards Climate Friendly Food	The Climate Programme for Finnish Agriculture presents a total of 76 measures to facilitate. By improving sustainability in a comprehensive way it is also possible to increase the profitability of production. The objective is to improve the energy and material efficiency and reduce emissions per litre or kilogram of production. Key measures identified in the climate programme for Finnish agriculture: carbon sequestration into soil; measures relating to the use of peatlands; plant breeding; plant and animal health and preventing the spread of invasive alien species; handling and treatment of manure and more accurate nitrogen fertilisation; energy efficiency and the production and consumption of renewable energy; reducing food loss all through the food system; changes towards a more plant-based diet	Climate Programme for Finnish Agriculture
Agri-cultural land	The Medium-term Plan for Climate Change Policy (2017)	In medium-term plan for agriculture measures to cut down GHG emissions includes: cultivation of organic soils on a multi-annual basis without tillage, lifting of groundwater level (controlled subsurface drainage) on organic agriculture lands, afforestation of organic soils; promotion of biogas production.	The Medium-term Plan for Climate Change Policy (2017)
Forest land	National Energy and Climate Strategy (2016)	In the energy and climate strategy actions aimed at increase sinks as well as decrease emission in the LULUCF sector are: ensuring the sustainable use and management of forests (incl. biodiversity), especially through balanced implementation of the National Forest Strategy emphasizing forest health, growth and carbon sinks; investigating possibilities to increase	National Energy and Climate Strategy (2016)

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
		afforestation; defining and implementing measures to reduce deforestation; developing farming to increase sinks and launching a pilot project to increase sinks on farms. Developing measures to monitor soil carbon sequestration in agricultural soils; studying the influence of CAP to soil carbon. Preparing proposals how in the renewal of CAP, farmers could be encouraged to increase sinks. The actions in the energy and climate strategy also include enhancing long term carbon storages in HWP through promoting the use of wood in construction.	

In Finland, the most feasible tool to motivate farmers to change soil management is the common agricultural policy and especially the environmental payments in it. Current environmental payments (2015-2020) likely affecting GHG emissions from cultivated peat soils are controlled drainage (targeted to peat soils or acid sulfate soils), nature management grasslands (partly targeted to peat soils), winter-time vegetation cover and different biodiversity measures also increasing the vegetation cover.

Climate Act of Finland requires climate plans to be prepared for each sector. Mid-term climate plan has been published and the measures planned for agriculture are mainly targeted to cultivated peat soils (Ministry of the Environment, 2017). The measures listed are favouring perennial cropping on peat soils, raising ground water table by controlled drainage and afforestation including paludicultural forest. However, there are no mechanisms in place for promoting afforestation yet. The government program published in 2019 also lists afforestation and paludiculture as potential measures, so these may be incentivized in the future.

Concerning forestry, until 2014 the Forest Act in Finland regulated quite tightly how forests must be managed. Accordingly, the predominant form of forest management, also on organic soils, has been rotation-based even-aged management (EM). The purpose of forest management in EM is to achieve a nearly coeval cohort of trees and eventually harvest and regenerate the forest by final felling followed by soil preparation and planting, seeding, or using natural regeneration with seed-trees. EM further involves intermediate thinnings from below to improve the growth and vitality of the remaining dominant trees. Ditch network maintenance (DNM) operations are recommended every 20-40 years to sustain and improve drainage conditions. After clear-cutting, some type of soil preparation in conjunction with DNM, e.g., ditch-mounding, is considered necessary to establish a new tree stand and lower the ground water table (GWT) that is temporarily raised by harvesting the tree stand that has significant evapotranspiration capacity and thus regulates the GWT in addition to the ditches.

In many organic forest soils, the concentrations of other nutrients relative to that of nitrogen are often sub-optimally low for tree growth. During the 1970's, especially, fertilization with phosphorus, potassium and boron was recommended for organic forest soils, and carried out in large areas. During the past few decades, fertilization activity has been relatively low. Currently, fertilization with wood ash is discussed intensively, since it would in many cases improve tree growth on organic forest soils in an economically feasible manner (e.g., Moilanen, Hytönen, Hökkä, & Ahtikoski, 2015), with few if any harmful environmental impacts (Huotari et al., 2015). Logistic challenges still constrain extensive ash application.

Nutrient-rich drained organic forest soils are currently recognized as a significant source of soil greenhouse gas emissions in the national greenhouse gas inventory (e.g., Statistics Finland, 2019). Emissions are generally the higher the deeper the GWT is (Paavo Ojanen et al., 2013). This is currently not accounted for in the greenhouse gas inventory, because so far there have been no means to produce GWT estimates to the National Forest Inventory data that is the basis for the greenhouse gas inventory. Environmental damage is also caused by sediment, nutrient and carbon release to receiving water bodies after DNM (e.g., Nieminen et al., 2010) and clear-cuts (Mika Nieminen et al., 2015; Xiao, 2015). A number of options have been proposed to manage water quality after DNM (Haahti et al., 2018; Mika Nieminen et al., 2017) and clear-cut (Mika Nieminen et al., 2018). Water protection structures inevitably increase the costs of timber production on drained organic soils, while not necessarily efficient in managing water quality. From the economic viewpoint a general problem in EM on drained organic soils is that major investments are needed to establish the forest stand and sustain its growth. Soil preparation, artificial regeneration, DNM and pre-commercial thinning each incur expenses. Furthermore, in EM the majority of the investments occur during the stand establishment (i.e., at the beginning of the rotation) while the revenues are realized at the end of the rotation.

The revised Forest Act has since 2014 allowed a broader range of forest management options, including uneven-structured management with selective cuttings, as well as other forms of continuous-cover management (M. Nieminen et al., 2018). Since EM has negative impacts on several ecosystem services and is less profitable on organic soils (Kojola et al., 2012) than in mineral-soil forests (e.g., Hynynen et al., 2015), the demand for alternative management options, such as continuous cover management, has increased. However, the area managed with continuous forest cover is still small, and the actual extent of it is not well known due to some gaps in how the statistics are collected.

1.3.3 Germany

In Germany, 61.5% of total organic soils are occupied by grassland, 22.0% - by cropland, 8.5% - by forest land, 1.1% - by peat extraction area, 1.1% by flooded wetlands and 5.7% - by other wetlands (according to the IPCC (Intergovernmental Panel on Climate Change) land use definitions; GHG Inventory Submissions 2019).

Emission factors used to calculate carbon stock changes in organic soils in different land use types within National GHG Inventory 2019 are summarized in Table 9. The biggest net carbon stock change in organic soils per area (-28.96 t C ha^{-1}) is indicated for peat extraction areas.

Table 9: Emission factors used to calculate carbon stock changes in organic soils in different land use types in Germany (National GHG Inventory 2019)

Land use		Net carbon stock change in organic soils per area, t C ha⁻¹
Category	**Sub-category**	
Forest land	Forest land remaining forest land	-2.22
	Land converted to forest land (average)	-2.22
	Cropland converted to forest land	-2.22
	Grassland converted to forest land	-2.22
	Wetlands converted to forest land	-2.22
	Settlements converted to forest land	-2.22
	Other land converted to forest land	-2.22
Cropland	Cropland remaining cropland	-8.10
	Land converted to cropland (average)	-8.10
	Forest land converted to cropland.	-8.10
	Grassland converted to cropland	-8.10
	Wetlands converted to cropland	-8.10
	Settlements converted to cropland	-8.10
	Other land converted to cropland	-8.10
Grassland	Grassland remaining grassland	-6.23
	Land converted to grassland (average)	-6.42
	Forest land converted to grassland	-5.84
	Cropland converted to grassland	-6.61
	Wetlands converted to grassland	-6.18
	Settlements converted to grassland	-6.05
	Other Land converted to grassland	-6.86
Wetlands	Wetlands remaining wetlands (average)	-8.68
	Peat extraction remaining peat extraction	-28.96
	Flooded land remaining flooded land	NO
	Other wetlands remaining other wetlands	-4.94
	Land converted to wetlands (average)	-3.97
	Land converted to peat extraction	NO
	Land converted to flooded land	NO
	Land converted to other wetlands (average)	-4.94
	Forest land converted to other wetlands	-4.94
	Cropland converted to other wetlands	-4.94
	Grassland converted to other wetlands	-4.94
	Settlements converted to other wetlands	-4.94
	Other land converted to other wetlands	NO
Settlements	Settlements remaining settlements	-7.40
	Land converted to settlements (average)	-7.40
	Forest land converted to settlements	-7.40

Land use		Net carbon stock change in organic soils per area, t C ha^{-1}
Category	**Sub-category**	
	Cropland converted to settlements	-7.40
	Grassland converted to settlements	-7.40
	Wetlands converted to settlements	-7.40
	Other Land converted to settlements	-7.40
Other land	Other land	NO

Emission factors for calculation of emissions and removals from drainage and rewetting and other management of organic soils for different land use categories in Germany are summarized in Table 10 (National GHG Inventory 2019).

Table 10: Emission factors for calculation of emissions from drainage and rewetting and other management of organic soils in Germany

Land use	Type of soil	Emission factors		
		CO_2, kg CO_2 ha^{-1}	N_2O-N, kg N_2O-N ha^{-1}	CH_4, kg CH_4 ha^{-1}
Forest land	Drained organic soils	IE	1.37	4.58
Cropland	Drained organic soils	IE	-	26.00
Grassland	Drained organic soils	IE	-	19.09
Wetlands, Peat extraction lands	Other organic soils	IE	0.85	11.19
Wetlands, Other lands	Other organic soils	IE	0.30	15.20
Settlements	Total organic soils	IE	2.69	IE

The German climate action plan 2050 sets the target for the LULUCF sector to continue to be a net sink in future. Official projections of the Federal Government show that this will not be the case any more from 2020 onwards as forest sinks are declining if no additional measures like rewetting and alternative use of organic soils are undertaken.

Therefore, the climate action plan 2050 lists several measures directed to organic soils / peatlands in chapter 5.6. of the Climate Action Plan 2050 (*Climate Action Plan 2050, Principles and goals of the German government’s climate policy*, 2016).

Measures include:

- expansion of funding programmes to conserve peatlands, and management practices that are appropriate for local conditions.
- Germany’s federal government is working toward an agreement with the Länder on the conservation of peatlands whose aim would be to conserve existing peatlands and create incentives for investments in water management to protect peatlands.
- German government will examine the possibility of consistent, permanent funding for paludiculture under EU Common Agricultural Policy (CAP).

- Pilot projects and measures to protect peatlands and promote climate-compatible management of water levels, Federal government will fund 4 long-term pilot projects for examine climate-friendly management and continued use.
- Peat use reduction for horticulture: German government will implement requirements for the use of peat substitutes in guidelines on awarding public procurement contracts for gardening and landscape architecture.
- Research programme on peat substitutes and expand the advisory and information measures.

These general measures have been specified in German’s recently adopted “Klimapaket 2030” (BMU, 2019) in chapter 3.4.7.3. It states the following activities to be tackled to reach Germany’s emission reduction targets till 2030:

- Adjustments of existing legal and promotion of legal basic conditions with the goal of guaranteeing an organic soil protection as effective as possible,
- appropriate protection of wetlands and peat areas entered in the EU CAP conditionality with the GAEC standard including an ambitious arrangement
- creation of new funding instruments, including the financing necessary for it for programs for the durable re-wetting of organic soils
- intensification of research and development measures, planned in the current GAP suggestion.

Additionally, several projects on the national level working on the development of management practices on organic soils and stakeholder involvement, funded by different national funding schemes. In the project “MoorDialog” by the Greifswald Mire Centre funded by the National Climate Initiative (NKI) a publication on climate-friendly management practices and best-practice examples has been published in early 2019 which summarised the state of the art in the field (Abel et al., 2019).

1.3.4 Latvia

In Latvia, 41.3% of total organic soils are occupied by forest land, 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 wetlands (according to the IPCC (Intergovernmental Panel on Climate Change) land use definitions; GHG Inventory Submissions 2019).

Emission factors used to calculate carbon stock changes in organic soils in different land use types within National GHG Inventory 2019 are summarized in Table 11. The biggest net carbon stock change in organic soils per area (-7.90 t C ha^{-1}) is indicated for cropland and settlements.

Table 11: Emission factors used to calculate carbon stock changes in organic soils in different land use types in Latvia (National GHG Inventory 2019)

Land use		Net carbon stock change in organic soils per area, t C ha^{-1}
Category	Sub-category	
Forest land	Forest land remaining forest land	-0.52

Land use		Net carbon stock change in organic soils per area, t C ha^{-1}
Category	**Sub-category**	
	Land converted to forest land (average)	-0.52
	Cropland converted to forest land	-0.52
	Grassland converted to forest land	-0.52
	Wetlands converted to forest land	-0.52
	Settlements converted to forest land	NO
	Other land converted to forest land	NO
Cropland	Cropland remaining cropland	-7.90
	Land converted to cropland (average)	-7.90
	Forest land converted to cropland	-7.90
	Grassland converted to cropland	-7.90
	Wetlands converted to cropland	-7.90
	Settlements converted to cropland	NO
	Other land converted to cropland	NO
Grassland	Grassland remaining grassland	-6.10
	Land converted to grassland (average)	-2.26
	Forest land converted to grassland	-6.10
	Cropland converted to grassland	-6.10
	Wetlands converted to grassland	6.10
	Settlements converted to grassland	NO
	Other Land converted to grassland	NO
Wetlands	Wetlands remaining wetlands (average)	-0.22
	Peat extraction remaining peat extraction	-2.80
	Flooded land remaining flooded land	IE
	Other wetlands remaining other wetlands	NA
	Land converted to wetlands (average)	-2.27
	Land converted to peat extraction	NO
	Land converted to flooded land	IE
	Land converted to other wetlands	-2.71
Settlements	Settlements remaining settlements	-7.90
	Land converted to settlements (average)	-7.90
	Forest land converted to settlements	-7.90
	Cropland converted to settlements	-7.90
	Grassland converted to settlements	-7.90
	Wetlands converted to settlements	-7.90
	Other Land converted to settlements	NO
Other land	Other land	NO

Emission factors for calculation of emissions and removals from drainage and rewetting and other management of organic soils for different land use categories in Latvia are summarized in Table 12 (National GHG Inventory 2019).

Table 12: Emission factors for calculation of emissions from drainage and rewetting and other management of organic soils in Latvia

Land use	Type of soil	Emission factors		
		CO_2, kg CO_2 ha^{-1}	N_2O-N, kg N_2O-N ha^{-1}	CH_4, kg CH_4 ha^{-1}
Forest land	Drained organic soils	IE	2.80	8.94
	Rewetted organic soils	1833.33	NA	288.00
Cropland	Drained organic soils	IE	-	1088.19
Grassland	Drained organic soils	IE	-	73.45
Wetlands, Peat extraction lands	Drained organic soils	29273.55	0.30	32.90
	Rewetted organic soils	2713.33	NA	288.00

Climate change mitigation targeted measures (LULUCF actions) applied to managed organic soils (mostly indirectly, meaning - although measures are not directly attributed to the management of organic soils, impact persists) are reported by Lithuania under Article 10 of the LULUCF Decision (LULUCF Actions Plans, initial and progress reports submitted between 2014 and 2018) 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 (MMR_PAMs, 2017) are summarized in Table 13. Climate change mitigation actions are based on the measures of the Latvian Rural Development Programme 2014-2020 (hereinafter referred to as RDP 2014-2020). Latvia’s RDP 2014-2020 is approved by the European Commission on 13 February 2015. The largest reduction in emissions is ensured by measures to be implemented in forest land.

Table 13: LULUCF actions applied to organic soils management in Latvia

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
Measures in cropland			
Cropland	Development and adaptation of drainage systems in cropland	The measures of the activity aimed on climate change mitigation are reconstruction and improvement of existing drainage systems in cropland to maintain and increase economic value of land and productivity of crops on drained lands. The measure has direct and indirect impact on GHG emissions in short and in long term. Soil carbon pool is highly affected in cropland.	2014-2020, Measure is integrated in the complex measure “Investments in physical assets: Support for investments in infrastructure related to development, modernization or adaptation of agriculture and forestry – drainage systems” of Rural Development Programme 2014-2020 (RDP 2014-2020), support for measure is defined in the 30.09.2014 Regulation of the Cabinet of Ministers No. 600.
Cropland	Support to introduction and promotion of integrated horticulture	The measure applies to the establishment of new orchards on existing cropland. Implementation of the measure will affect carbon stock in living biomass and soil carbon pool; respectively, it will reduce CO_2 emissions. Change of the land management system, particularly, establishment of continuous ground vegetation, will affect N_2O and CH_4 emissions.	2014-2020, Measure is integrated in a complex measure “Commitments of agri-environment and climate: Use of environmentally- friendly methods in horticulture [a better governance, reduction of use of mineral fertilizer and pesticide (including integrated production)]” of RDP 2014-2020, support for measure is defined in the

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
			07.04.2015 Regulation of the Cabinet of Ministers No.171.
Cropland	Growing of legumes	The measure applies to the use of legumes in mixture with other crops in cropland, resulting in higher inputs of organic material into soil and partial replacement of mineral fertilizers with nitrogen fixing plants.	2014-2020, Measure is integrated in the complex measure "Commitments of agri-environment and climate: Establishment of environmentally friendly land by cultivation of plants for nectar extraction" of RDP 2014-2020, support for measure is defined in the 07.04.2015 Regulation of the Cabinet of Ministers No.171.
Cropland	Maintenance of biodiversity in grasslands	Leaving a certain area of cropland out of conventional cropping system, if the area is not afforested or used for perennial crop production, in general will not lead to GHG emission reduction or increase of CO_2 removals, because reduction of the field size in one place should be compensated by increase of a field area in other place to maintain production, if no other productivity measures are applied. However, GHG emissions are mitigated if management activities on organic soil are reduced.	2014-2020, Measure is integrated in the complex measure "Commitments of agri-environment and climate: Maintenance of biodiversity in grasslands" of RDP 2014-2020, support for measure is defined in the 07.04.2015 Regulation of the Cabinet of Ministers No.171.
Measures in forest land			
Forest land	Development and adaptation of drainage systems in forest land	The measures of the activity aimed on climate change mitigation are reconstruction and improvement of existing drainage systems in forest land to maintain and increase economic value of land and productivity on drained lands. The measure has a direct and indirect impact on GHG emissions in short and in long term. Living and dead biomass carbon pool is highly affected (increased in short and long term prospective) and can be quantified following to existing forest management models.	2014-2020, Measure is integrated in the complex measure "Investments in physical assets: Support for investments in infrastructure related to development, modernization or adaptation of agriculture and forestry – drainage systems" of RDP 2014-2020, support for measure is defined in the 30.09.2014 Regulation of the Cabinet of Ministers No. 600.
Forest land	Afforestation and improvement of stand quality in naturally afforested areas	The scope of afforestation is economically and environmentally efficient utilization of former farmlands (mainly land with low fertility), which are not any more used for food of fodder production. Afforestation secures accumulation of CO_2 in living and dead biomass, litter and soil.	2014-2020, Measure "Investments in expanding of forest area and enhancing viability of forests: Support for afforestation and forest land establishment" is integrated in the RDP 2014-2020, support for measure is defined in the 04.08.2015Regulation of the Cabinet of Ministers No.455.
Forest land	Regeneration of forest stands after natural disasters	The measure supports regeneration of forests after natural disasters, like forest fires and strong storms, as well as reconstruction of diseased valueless forest stands. The measure will affect carbon stock in living biomass, dead wood, litter and soil carbon pools; respectively, it is aimed to increase CO_2 removals.	2014-2020, Measure "Investments in expanding of forest area and enhancing viability of forests: Support for prevention and regeneration of forest stands after forest fires, natural damages and catastrophes" is integrated in the RDP 2014-2020, support for measure is defined in the 04.08.2015 Regulation of the Cabinet of Ministers No.455.

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
Forest land	Preventive measures of forest damages	The scope of the measure is to maintain forest fire prevention system, including reconstruction of existing and building of new fire observation towers.	2014-2020, Measure "Installation and improvement of forest fire, pest and diseases monitoring facilities and communication equipment" is integrated in the RDP 2014-2020, support for measure is defined in the 14.06.2016 Regulation of the Cabinet of Ministers No.381.
Forest land	Improvement of ecological value and sustainability of forest ecosystems	The scope of the measure is to support pre-commercial thinning of young stands in private forests to ensure sustainable forest management practices aimed to increase economic and ecological value of forests in long term.	2014-2020, Measure "Investments in expanding of forest area and enhancing viability of forests: Support for investments in improvement of ecological value and sustainability of forest ecosystems" is integrated in the RDP 2014-2020, support for measure is defined in the 04.08.2015 Regulation of the Cabinet of Ministers No.455.

1.3.5 Lithuania

In Lithuania, 41.4% of total organic soils are occupied by forest land, 28.0% - by wetlands (excluding peat extraction areas and flooded wetlands), 12.3% - by flooded wetlands, 8.3% - by cropland, 8.3% - by grassland and 1.7% - peat extraction areas (according to the IPCC (Intergovernmental Panel on Climate Change) land use definitions; GHG Inventory Submissions 2019).

Emission factors used to calculate carbon stock changes in organic soils in different land use types within National GHG Inventory 2019 are summarized in Table 14. The biggest net carbon stock change in organic soils per area (-14.51 t C ha^{-1}) is indicated for peat extraction areas.

Table 14: Emission factors used to calculate carbon stock changes in organic soils in different land use types in Lithuania (National GHG Inventory 2019)

Land use		Net carbon stock change in organic soils per area, t C ha^{-1}
Category	Sub-category	
Forest land	Forest land remaining forest land	IE
	Land converted to forest land(8)	IE
Cropland	Cropland remaining cropland	IE
	Land converted to cropland(10)	NO, IE
Grassland	Grassland remaining grassland	IE
	Land converted to grassland	NO, IE
Wetlands	Wetlands remaining wetlands	-0.58
	Peat extraction remaining peat extraction	-14.51
	Flooded land remaining flooded land	NE
	Other wetlands remaining other wetlands	NE
	Land converted to wetlands	NO, NE, NA

Land use		Net carbon stock change in organic soils per area, t C ha^{-1}
Category	**Sub-category**	
Settlements	Settlements remaining settlements	NO
	Land converted to settlements	-0.37
	Forest land converted to settlements	NO
	Cropland converted to settlements	-5.26
	Grassland converted to settlements	-0.22
	Wetlands converted to settlements	NO
	Other Land converted to settlements	NO
Other land	Other land	NO

Emission factors for calculation of emissions and removals from drainage and rewetting and other management of organic soils for different land use categories in Lithuania are summarized in Table A (National GHG Inventory 2019).

Table 15: Emission factors for calculation of emissions from drainage and rewetting and other management of organic soils in Lithuania

Land use	Type of soil	Emission factors		
		CO_2, kg CO_2 ha^{-1}	N_2O-N, kg N_2O-N ha^{-1}	CH_4, kg CH_4 ha^{-1}
Forest land	Drained organic soils	2493.33	0.44	NE
Cropland	Drained organic soils	18333.33	-	NE
Grassland	Drained organic soils	916.67	-	NE
Wetlands, Peat extraction lands	Drained organic soils	IE	0.72	NE

Climate change mitigation targeted measures (LULUCF actions) applied to managed organic soils (mostly indirectly, meaning – although measures are not directly attributed to the management of organic soils, impact persists) are reported by Lithuania under Article 10 of the LULUCF Decision (LULUCF Actions Plans, initial and progress reports submitted between 2014 and 2018) 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 (MMR_PAMs, 2017) are summarized in Tables A. This list includes all relevant measures that cover activities as agriculture land management, reversion of land degradation through revegetation or afforestation, reforestation and other forest management. All the listed measures are set in Inter-institutional action plan on the implementation of the Goals and Objectives for 2013-2020 of the Strategy for the National Climate Change Management Policy, National Forestry Sector Development Programme for 2012-2020 and mostly are supported by the Rural Development Programme 2014-2020.

Table 16: LULUCF actions applied to organic soils management in Lithuania

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
Agricultural land use sector			
Agricultural land	Minimization of the direct and indirect nitrogen compounds emissions	Promote use of environmentally friendly management methods in agriculture, in order to protect status of water and soil.	In Inter-institutional action plan on the implementation of the

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
	from agriculture activities: create forecasting system for crops diseases and other pests		Goals and Objectives of the Strategy for the National Climate Change Management Policy (further in the text referred to as the Strategy for the National Climate Change Management Policy)
Agricultural land	Implementation of soil monitoring system and improvement of agricultural methods in order to minimize the loss of soil layer: the analysis of soil agrochemical characteristics	Promote use of environmentally friendly management methods in agriculture, in order to protect status of water and soil.	
Agricultural land	Support for environmentally friendly agriculture management programs	In order to avoid degradation of land resources due to increased intensity of agricultural activities, the use of chemicals and erosion, it is necessary to support restoration and conservation of biodiversity and landscape, including Natura 2000 sites, reduce risks of surface water pollution and promote the deployment of high natural value of organic farming. Organic farming will be encouraged in less favourable areas for agriculture activities, in order to reduce the risk of soil erosion.	The Strategy for the National Climate Change Management Policy Lithuania's Rural Development Programme 2014 – 2020.
Agricultural land	Development of the consulting services on agriculture management activities	Support the consultations of farmers and forest managers by introducing them to application of the climate and environment friendly agricultural practices.	The Strategy for the National Climate Change Management Policy Lithuania's Rural Development Programme 2014 – 2020.
Agricultural land	Support of research activities related to development of adaptive agricultural plant species to climate change	Due to climate change the risk of extreme climatic events is increasing, the new diseases and pest are developing as well as animal disease outbreaks becoming more frequent thus a need of effective risk management in the agriculture and forest sectors is urgent.	The Strategy for the National Climate Change Management Policy Rural Development Plan 2014 – 2020.
Forestry			
Forest land	Afforestation of the abandoned and non useful for agriculture activities land	In order to reduce atmospheric pollution originated from agricultural activities and contribute to climate change mitigation as well as to reduce the area of the abandoned land, the afforestation of these lands and the restoration of damaged forests must be supported. The agriculture methods involving the use of multiple grassland and application of crop rotation technologies will be supported as well. Greenhouse gas affected: CO_2.	The Strategy for the National Climate Change Management Policy Lithuania's Rural Development Programme 2014 – 2020
Forest land	Sustainable forestry: Promoting the use of biomass for energy production	In Lithuania of all the renewable energy sources the biomass, because of its volume and stable properties, is one of the most important, but the potential of biomass for biomass production is still poorly utilized. In order to reduce the negative impact of the under-utilization of biomass to the environment and especially the climate change the use of biomass must be promoted. Greenhouse gas affected: CO_2.	The Strategy for the National Climate Change Management Policy National Forestry Sector Development Programme for 2012 – 2020

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
Forest land	Investment in the resistance and environmental value of the forest ecosystems	Lithuanian Rural Development Programme 2014-2020 supports the conservation of forest ecosystems that are necessary to maintain the ecological balance of the country. Greenhouse gas affected: CO_2.	The Strategy for the National Climate Change Management Policy National Forestry Sector Development Programme for 2012 – 2020
Forest land	Reconstruct a potential of the forests in forests impacted by the fire and other natural disturbances related with climate change and implement the prevention measures	Lithuania’s Rural Development Programme 2014-2020 provides investment support for restoration of forest damaged by fires and other natural disasters including pests and diseases, as well as to support the implementation of forest fire prevention measures. Greenhouse gas affected: CO_2.	The Strategy for the National Climate Change Management Policy National Forestry Sector Development Programme for 2012 – 2020
Forest land	Reducing of the use of chemical material for plant protection in forest area by changing them in to biological or mechanical	Lithuania’s Rural Development Programme 2014-2020 supports the conservation of forest ecosystems that are necessary to maintain the ecological balance of the country. Greenhouse gas affected: CO_2.	The Strategy for the National Climate Change Management Policy National Forestry Sector Development Programme for 2012 – 2020
Forest land	Preparation of the inventory and the recommendations for management and restoration of degraded forests ecosystems	To reach the recreation of degradable and already degraded forest ecosystems. Greenhouse gas affected: CO_2.	The Strategy for the National Climate Change Management Policy
Other measures			
All	Revision of River Basin Management Plans	Main objective of River Basin Management plans is to ensure good status of surface and groundwater. RBMP covers all territory of Lithuania.	The Strategy for the National Climate Change Management Policy
All	Improvement of aboveground and underground water monitoring – supplement it with climate change impact factors	To ensure the continuing improving and renewal of meteorological and hydrological monitoring system.	The Strategy for the National Climate Change Management Policy
All	Preparation of Lithuania’s climate monitoring digital data archive	To create a geographical database of climate change	The Strategy for the National Climate Change Management Policy
All	Reconstruction of drainage systems and land reclamation canals	Lithuania is in the area of the excessive humidity: about 90 % of the total crop production is growing on reclaimed lands. As a result, crop irrigation is not widely used; irrigation consumes a relatively small amount of water. It is drained about 2.9 million ha using a drainage system (respectively 86.3% and 77.4 % of agricultural land). The average age of reclamation facilities is about 40 years, during this period, most of the facilities have not been renovated and depreciation reaching 57 %. Completely worn out land reclamation installations are in area of 222 kha (6.6 % of agricultural land)	The Strategy for the National Climate Change Management Policy Lithuania’s Rural Development Programme 2014 – 2020
All	Improvement of the	To encourage scientific research and	The Strategy for the

Land use type	Climate change mitigation targeted measures	Objectives and short description	Implementation period, policy
	research program "Sustainability of agro-, forest and water ecosystems" and the execution of research projects, approve the final report of this program in which all the scientific reach results will be reviewed.	experimental development as well as innovation in climate change field and to maintain the efficient use of allocated funds	National Climate Change Management Policy
All	Implementation of the program for public awareness raising about measures in Environment protection sector in 2014-2020 (particularly on climate change mitigation and adaptation measures).	Raising public awareness regarding climate change impacts and possible prevention measures in agriculture and forestry sectors.	The Strategy for the National Climate Change Management Policy
All	Preparation of nature protection plans for territories important to habitat and birds reservation.	To stabilize the decrease of biodiversity because of climate change impact in Lithuania and Baltic biogeographical region.	The Strategy for the National Climate Change Management Policy
All	Planning of protected areas, modernization and update of cadastre, strengthening of monitoring system and capacities of territories management.	To develop system of protected areas, to reconstruct and multiply number of natural elements of landscape in these areas	The Strategy for the National Climate Change Management Policy
All	Strengthening the control of release of genetically modified organisms in to environment, inspection of entities involved in the limited use of genetically modified organisms.	The aim is to ensure that genetically modified organisms do not spread in environment and do not damage biodiversity and ecosystems.	The Strategy for the National Climate Change Management Policy

2. LOOKING FOR HIGH IMPACT APPROACHES IN THE MANAGEMENT OF NUTRIENT RICH ORGANIC SOIL – BENCHMARKING BY CURRENT KNOWLEDGE LEVEL AND POTENTIAL IMPACT

In Table 17 detailed assessment of relevant policies and measures listed by the EU Member States for reducing emissions from organic soils is shown according to Martineau et al. (2014); Paquel et al. (2017); *Updated Inventory and Assessment of Soil Protection Policy Instruments in EU Member States* (2017).

Table 17: Detailed assessment of relevant policies and measures listed by the EU Member States for reducing emissions from organic soils

Activities reported	GHG Impact –based on literature review	Abatement/ Sequestration	National Inventory Report (NIR) category
Biodiversity and nature conservation			
Subsidies for the conversion of arable land on organic soils to nature (Germany)	Restoration of wetlands helps to reduce GHG emissions from decomposition of peat and Restoring the natural water table of drained wetlands. With an increased water table in organic, carbon-rich soils, accumulation of organic substances is greater than the decomposition, which facilitates the conservation and accumulation of peat and reduces the carbon release from these soils. Nutritional regime is important to predict impact.	Large potential in the correct circumstances with a mitigation potential range for restoration of wetlands is 3.1 to 7.8 t CO_2 eq-1 ha^{-1} yr^{-1} (Frelih-Larsen et al., 2014). Opposite impact reported by other studies, e.g. LIFE REstore project in Latvia.	Cropland converted to Wetland
Rehabilitation of moorland and restoration of wetlands, protection of bogs	The relationship between wetlands/peatlands and GHG emissions is complex. The fluxes of CO_2, CH_4 and N_2O vary depending on the condition and hydrological status of the wetland. The amount and type of GHG emissions depend on the water saturation in the soil, climatic conditions and the nutrient availability. The drainage of wetlands and peatlands exposes organic carbon to the air, decomposition of the organic material occurs and emits CO_2. Drained organic soils with low water tables continue to degrade and to emit CO_2, until either drainage is reversed or all peat is lost. Saturated soils however create anaerobic conditions and can release CH_4. Effect of the measure is not proved in Baltic countries due to significant increase of CH_4 emissions and rather limited or no increase of CO_2 removals	Restoration of wetlands helps to reduce GHG emissions from decomposition of peat and restoring the natural water table of drained wetlands. With an increased water table in organic, carbon-rich soils, accumulation of organic substances is greater than the decomposition, which facilitates the conservation and accumulation of peat and reduces the carbon release from these soils.	Wetlands remaining Wetlands
Initiatives to limit consumption of peat in horticulture	Indirect – it is not clear how this demand based initiative will reduce the impact on peat extraction; the impact is not sufficiently proved by evaluation of life cycle of alternative products	Conservation of existing carbon stock	Wetlands
Protection and management of the Natura 2000 network	Indirect – protection is likely to preserve carbon stocks that might otherwise be lost; however, there are climate change related impact on carbon stocks e.g. degradation of sphagnum moss due to increase of temperature. In Baltic states there are	Conservation of existing Carbon Stock	Wetlands, Grassland, Forest Land, Cropland

Activities reported	**GHG Impact –based on literature review**	**Abatement/ Sequestration**	**National Inventory Report (NIR) category**
	insufficient evidences of net removals in conserved sites.		
Maintenance of biodiversity in grasslands	Reduced CO_2 and N_2O, emissions (LV Article 10 report)	Conversion of 1 ha of cropland to grassland considering 5.18% share of organic soils would reduce CO_2 emissions by 0.3 t CO_2 ha^{-1} yr^{-1} (LV Article 10 report)	Cropland converted to grassland
Nutrient, tillage, and water management			
Converting cropland from annual tillage crops to perennial crops	Converting cropland to perennial crops such as grass can sequester and retain carbon	Martineau et al., estimated the range as 0.6 – 2.0 t ha^{-1} yr^{-1} of carbon sequestered	Cropland converted to Grassland
Development and adaptation of drainage systems in cropland	More studies are necessary to evaluate impacts, particularly on non-CO_2 gases, of the measure on the basis of scientific results	Implementation of the measure in Latvia according to the tier 1 method will contribute to the net CO_2 removals in soil –1.32 t CO_2 ha^{-1} yr^{-1} during 20 years' period after implementation	Cropland remaining cropland
Grassland, grazing land and/or pasture management			
Pasture Suitable for carbon storage	The prevention of cultivation on high organic matter soil will maintain the carbon stock more effectively.	This activity reduced losses.	Grassland remaining Grassland
Preservation of HNV grassland	Prevention of grassland (without cultivation) will preserve the carbon stock.	Reduces carbon losses through cultivation.	Grassland remaining Grassland

In Latvia, within LIFE REstore project GHG emissions from organic soil depending on land use type were evaluated (Krīgere, Dreimanis, Kalniņa, Lazdiņš, et al., 2019c, 2019b, 2019a; Krīgere, Dreimnis, Siliņa, Kalniņa, et al., 2019; Krīgere, Kalniņa, Dreimanis, et al., 2019; Krīgere, Kalniņa, Ozola, et al., 2019; Lazdiņa, Krīgere, et al., 2019; Lazdiņa, Neimane, et al., 2019; Lazdiņš & Lupiķis, 2019, 2019). Within the LIFE REstore project GHG emissions from organic soil depending on land use type were evaluated to recommend the best management approaches of:

- peat soils in raised bogs and transition mires;
- organic soils in cropland and grassland, where the availability of nutrients has increased several times, compared to peat extraction fields, due to management activities.

Results of LIFE REstore project confirmed that a human intact bog is a net CO_2 sink. After drainage, peat decomposition and mineralization are increasing rapidly and CO_2 emissions occur, but CO_2 uptake in photosynthesis of growing plants does not compensate for CO_2 losses from the ecosystem, and as a result soil carbon stock is decreasing (Figure 8).

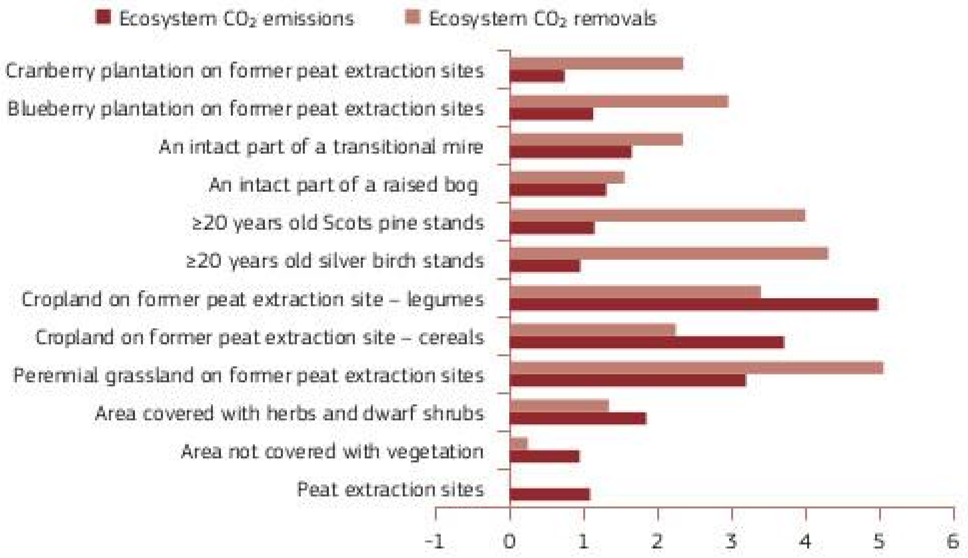

Figure 8: Ecosystem CO_2 removals and emissions, depending on land use type (Lazdiņš & Lupiķis, 2019)**.**

Smaller net emissions (the difference between emissions and CO_2 removals) were recorded in cranberry plantations, where the net emissions were 0.75 t CO_2-C ha^{-1} annually (Fig. 6). Although the annual amount of emissions in cranberry plantations (2.6 t CO_2-C ha^{-1} annually) is larger than in peat extraction fields (1.09 t CO_2-C ha^{-1} annually) and in abandoned peat extraction fields (0.95 t CO_2-C ha^{-1} annually), CO_2 capture by vegetation through photosynthesis can partially compensate for CO_2 emissions. Overall, it can be assumed that establishment of cranberry plantations on former peat extraction fields contributes to decrease of net CO_2 emissions. A similar situation arises, when an abandoned peat extraction site is afforested with conifers, where the average net CO_2 emissions equal to 0.96 t CO_2-C ha^{-1} annually. For a comparison – if peat extraction still continues, net emissions equal to 1.09 t CO_2-C ha^{-1} annually, in abandoned peat extraction fields that are not covered with vegetation – 0.95 t CO_2-C ha^{-1} annually, but in abandoned fields covered with vegetation that is not a tree stand – 1.85 t CO_2-C ha^{-1} annually. A decrease in CO_2 emissions, compared to herb and dwarf shrub vegetation development in a partially extracted peat field, is possible also if the abandoned peat extraction site if afforested with silver birch (net emissions – 1.15 t CO_2-C ha^{-1} annually) or a blueberry plantation is established on it (net emissions– 1.13 t CO_2-C ha^{-1} annually). The greatest positive effect of tree and shrub planting is caused by CO_2 sequestration in the living biomass. Transforming peat extraction fields into croplands, where cereals or other crops are cultivated, or into grassland, used for grazing or forage production, shows negative results. In this case CO_2 emissions significantly increase, and the net emissions reach 5.0 t CO_2-C ha^{-1} annually, 3.7 t CO_2-C ha^{-1} annually and 3.2 t CO_2-C ha^{-1} annually, accordingly, in croplands where cereals or legumes are cultivated and in grassland (Lazdiņš & Lupiķis, 2019).

In contrary to CO_2 emissions, CH_4 emissions usually decrease after drainage. This was confirmed also after summarizing LIFE REstore results on CH_4 emissions (Figure 9). Higher CH_4 emissions were found in intact transition mires and raised bogs, which were used in calculations to characterize GHG emissions at a steady stage conditions after rewetting. In transition mires and raised bogs CH_4 emissions reach 274 kg CH_4-C ha^{-1} annually and 133 kg CH_4-C ha^{-1} annually accordingly. The lowest CH_4 emissions were found in afforested cropland, where methane emissions do not exceed 1.0 kg CH_4-C ha^{-1} annually. In areas afforested with Scots pine, a small removal was found, i.e. emission values were negative (-1.4 kg CH_4-C ha^{-1} annually). It means that soil microorganisms are consuming methane. In this study it was concluded that rise of groundwater table contributes to increase in CH_4 emissions (Lazdiņš & Lupiķis, 2019).

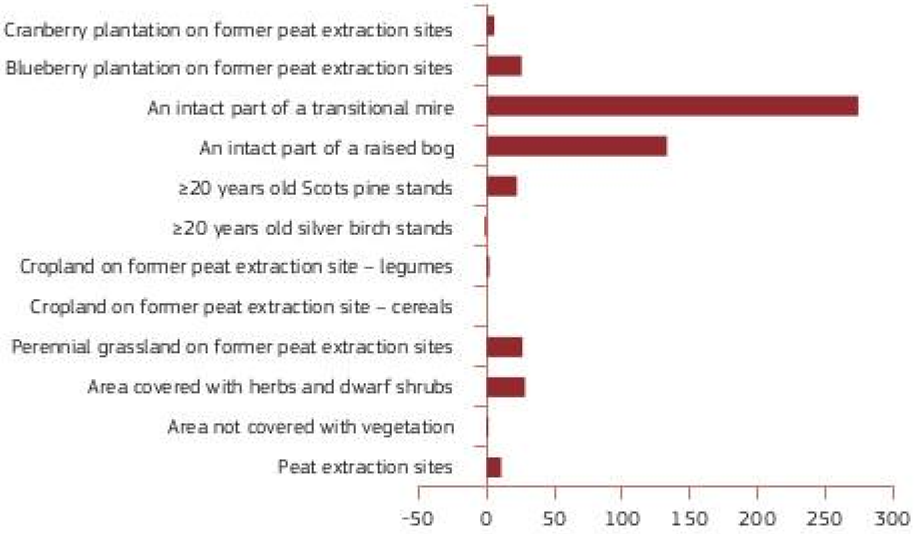

Figure 9: CH_4 emissions depending on land use type (Lazdiņš & Lupiķis, 2019).

The highest N_2O emissions, as expected, were found in cropland (Figure 10). Accordingly, in croplands, where cereals and legumes are cultivated, N_2O emissions are 7.8 kg N_2O-N ha^{-1} annually and 4.5 kg N_2O-N ha^{-1} annually. The relatively high N_2O emissions in cropland are related to the high amount of nitrogen (N) available to plants and microorganisms, provided by regular application of fertilizers. Considerable N_2O emissions were also found in transition mire and blueberry plantation, accordingly 1.4 kg N_2O-N ha^{-1} annually and 0.9 kg N_2O-N ha^{-1} annually. Also in blueberry plantations nitrogen fertilizer was applied, which is reflected in the results, however, fertilizer dosages are smaller than in intensively cultivated croplands. It is relatively harder to explain N_2O emissions from transition mires. Even more so because the total nitrogen content in transition mire soil is not higher than in raised bogs, cranberry plantations or peat fields, where N_2O emissions are insignificant. The most of N_2O emissions (> 80%) in transition mires are produced in March and April, when snow and frozen soil surface have melted. It is related to bacterial activity in soil and their interactions. Production of N_2O emissions is a complicated process, which is still not entirely clear. A significant rise in N_2O emissions in study objects in the spring months has increased the total annual N_2O emissions. In order to obtain more precise N_2O emission data, the frequency of data collection should be increased, particularly in the spring and summer months, when the impact of snow melting and fertilizer application can be observed (Lazdiņš & Lupiķis, 2019).

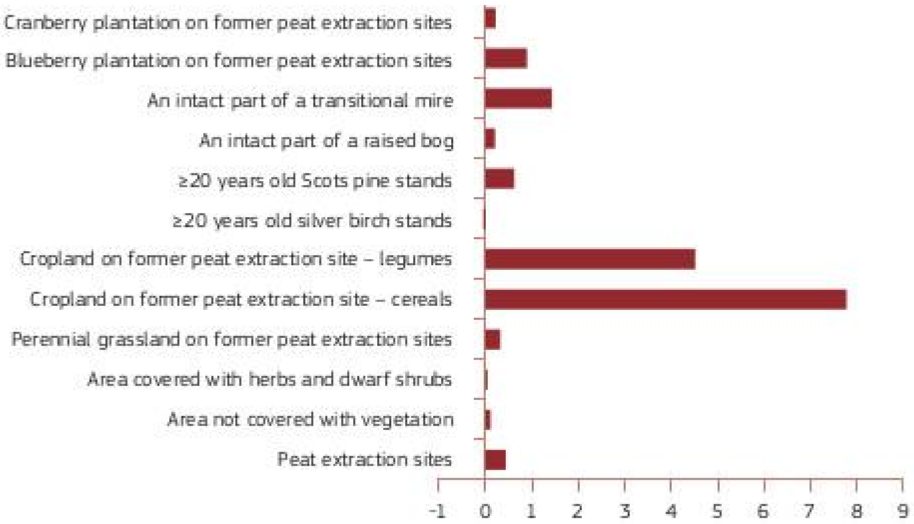

Figure 10: N_2O emissions depending on land use type (Lazdiņš & Lupiķis, 2019).

The cumulative GHG emissions from soil that reflect CO_2-C, CH_4-C and N_2O-N emissions in CO_2 equivalents are shown in Figure 11. The figure shows that from all the after-use scenarios of peat extraction areas viewed in this study the lowest GHG emissions from soil are ensured by afforestation with coniferous species and establishment of large cranberry plantation. The net emissions from soil in case of these scenarios accordingly are 4.3 t CO_2 eq. ha^{-1} annually and 5.2 t CO_2 eq. ha^{-1} annually. A similar amount of emissions is produced in silver birch stands (5.5 t CO_2 eq. ha^{-1} annually). It should be noted that CO_2 sequestration in tree biomass, deadwood and ground litter, which provide significant additional removals, are not included here. Whereas, if reclamation in an area is not carried out and it naturally overgrows with non-forest vegetation, the total GHG emissions are 7.9 t CO_2 eq. ha^{-1} annually. There are relatively good results from the blueberry plantation establishment scenario, where emissions are slightly lower (net emissions equal to 6.4 t CO_2 eq ha^{-1} annually), compared to an abandoned peat field covered with vegetation. However, in all the after-use scenarios the emissions are slightly higher, comparing with an active peat extraction site (net emissions equal to 4.2 t CO_2 eq ha^{-1} annually) or an abandoned peat field that is not covered with vegetation (3.3 t CO_2 eq. ha^{-1} annually). Increase in emissions is related to the increase in vegetation cover, which provides a favourable environment for microorganisms, and thus contributing to CH_4 and CO_2 emissions (Lazdiņš & Lupiķis, 2019).

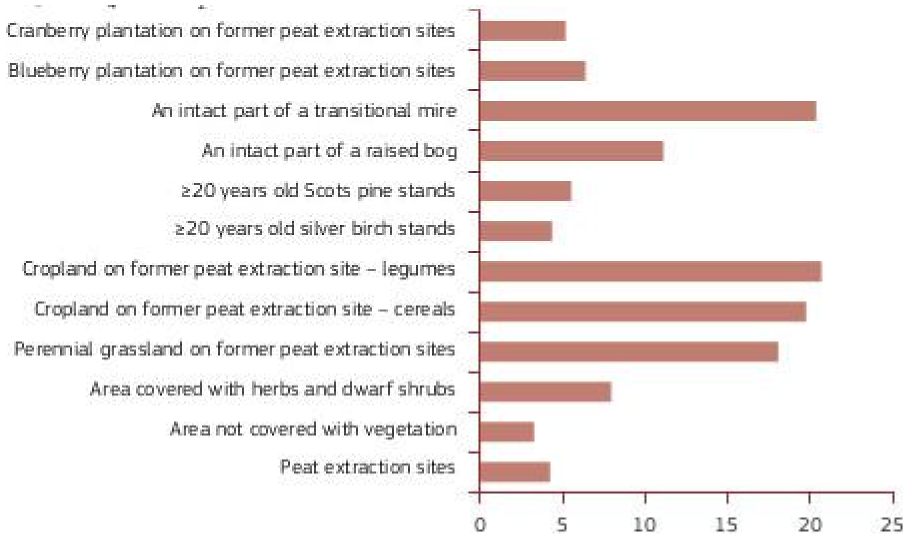

Figure 11: Net GHG (CO_2, CH_4, N_2O) emissions, recalculated to CO_2 equivalents (Lazdiņš & Lupiķis, 2019).

In the context of climate change mitigation, results of LIFE REstore project indirectly confirmed that the use of organic soil for agricultural purposes should be avoided, except conversion of cropland to pastures, because agricultural practises results in significant amount of emissions from soil. The best after-use scenarios for climate change mitigation from those assessed within the study, are afforestation with Scots pine or birch, which can be done on both raised bog and transition mire peat soil, and establishment of large cranberry plantations, which can be done in areas, where the layer of raised bog peat is thick enough (Lazdiņš & Lupiķis, 2019). The potential role of wet forests is insufficiently investigated.

2.1 Cropland

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 light-weight 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).

2.2 Grassland

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.

2.3 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) are beneficial for maintaining the carbon stocks in organic soil. Over-drainage should always be avoided. Although deepening the water table increases productivity, in Finland it is not necessary after the tree stand volume has exceeded 100–150 cubic metres per hectare (Sarkkola et al., 2010). After this threshold has been reached, the tree stand itself, through efficient transpiration, maintains sufficient drainage. In Latvia growing stock on peat soils

Drainage of forests on organic soils often leads to 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 (Paavo Ojanen et al., 2019).

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}. Average growing stock of different species in forests with nutrient rich drained and wet soils is compared in Figure 12 and 13. 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.

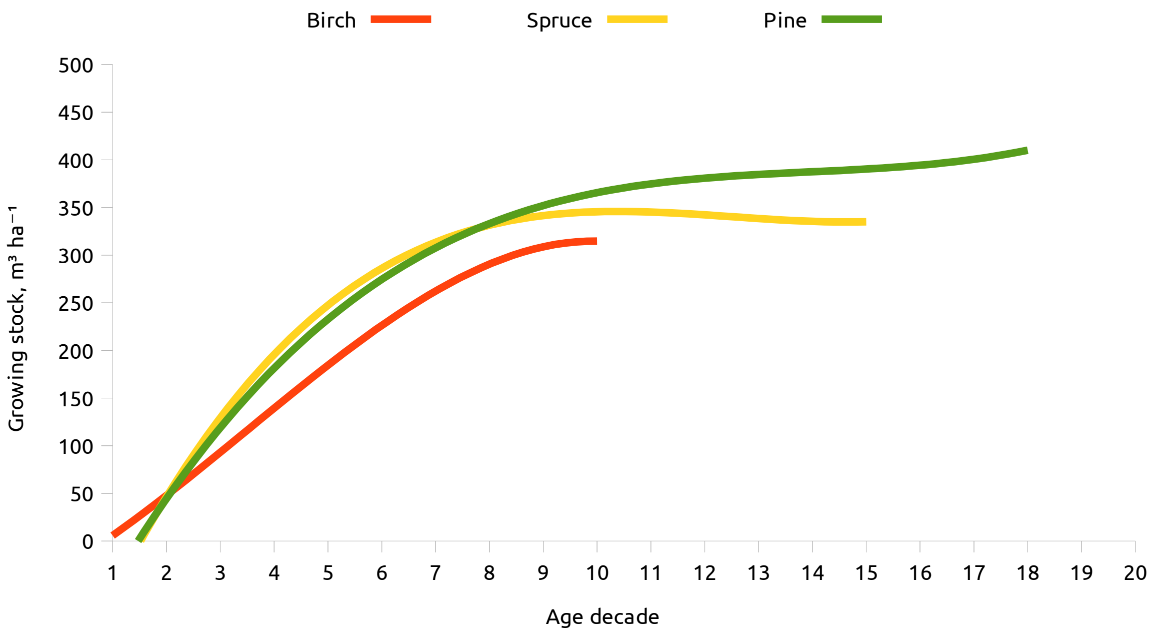

Figure 12: Growing stock in forests with drained organic soils in Latvia according to National forest inventory.

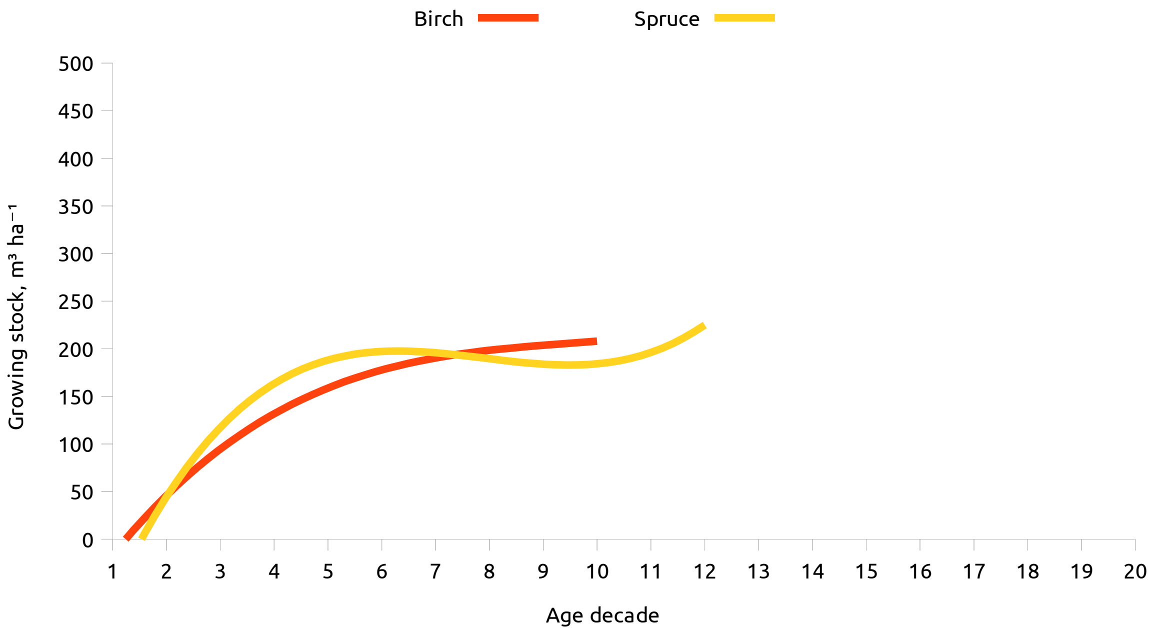

Figure 13: Growing stock in forests with wet organic soils in Latvia according to National forest inventory.

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.

3. APPROXIMATION OF POTENTIAL MITIGATION IMPACT AND WAY FORWARD

The scope of the project is to identify potentially efficient measures, which are not yet scientifically verified. Expert questionnaire is used to identify potential measures. Information about measures provided by experts is provided in Table 18.

Table 18: Contents of experts questionnaire about climate change mitigation measures

No	Type		Description
1.	Title		Simple and short title describing core of the measure.
2.	Substantiation of the impact		Brief description of impact of the measures.
3.	Criteria for site selection		Criteria for selection of suitable sites where the selected measures can be implemented to ensure the proposed effect. Country specific notes can be added.
4.	Addressed carbon pools and GHG emissions		Carbon pools positively or negatively affected by the measure.
5.	Country specific information	Methods and models applied for impact assessment at local and national level	Existing calculation methods (currently available) including assumptions for listing the measure under GHG emissions reduction targeted activities.
6.		How existing LPIS and other monitoring systems needs to be improved to verify the impact	Existing and necessary (not available yet) activity data sources and sources of information on carbon stock changes, which can be used in calculations.
7.		Duration of impact and supplementary measures to sustain the impact	Duration of the impact of the measure in years, additional activities which needs to be implemented to maintain the achieved mitigation effect or to ensure that the proposed impact will be achieved, like forest protection measures.
8.		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.
9.		Conformity with sustainability criteria	Conformity with sustainability criteria listed in the LULUCF regulation and national policies.
10.		Estimation of cost and benefit ratio	Information on implementation costs (direct and indirect - additional measures), investments and potential financial outcome by selling of wood (in case of additional increment).
11.		Interferences and synergies with other sectors, land uses and policies	Description of impact on other sectors, e.g. agriculture, and policies, e.g. reduction of CH_4 emissions and Hg output into water bodies.
12.		Status in national policy, existing support schemes	Description of existing support schemes at national level.
13.		References	Literature references and related projects.
14.	Applicability in other EU countries		Applicability of the measure in other countries, particularly, in TCM climate zone.
15.	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.

Summarized information about the proposed measures is provided in Annex 1; country specific information is analysed in following chapters. In total 41 measure is identified, the most of them are aimed at increase of productivity of forests, management of farmlands, risk management and land use changes (Figure 14). quantitative impact of the most of the measures cannot be estimated using existing data sources and scientific data. The most of the identified measures are not specific to organic soils and can be implemented in organic, as well as mineral soils.

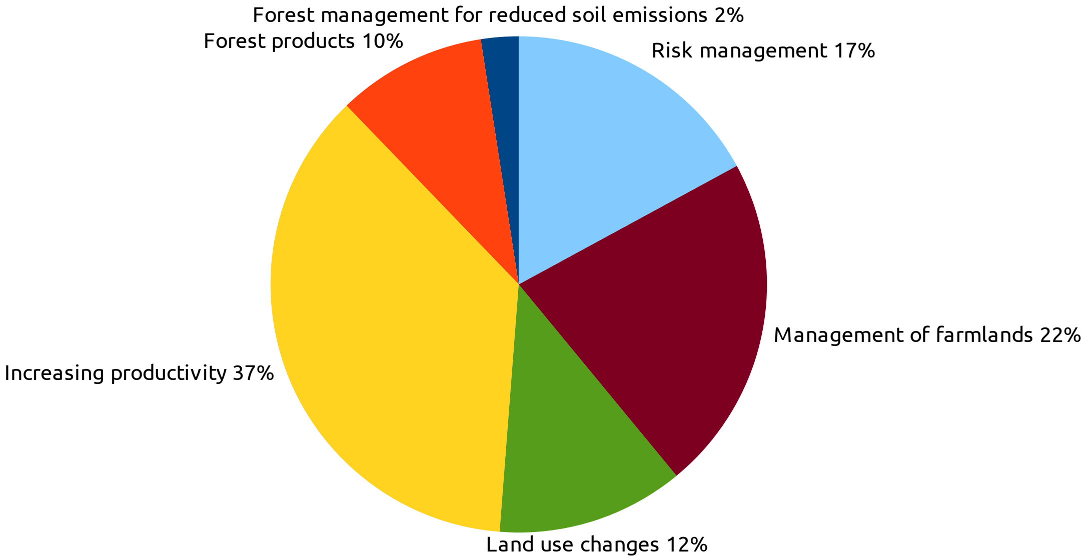

Figure 14: Types of identified climate change mitigation measures.

The most of the measures are addressed to forest lands, few measures can be implemented both in farmlands and forest lands (Figure 15).

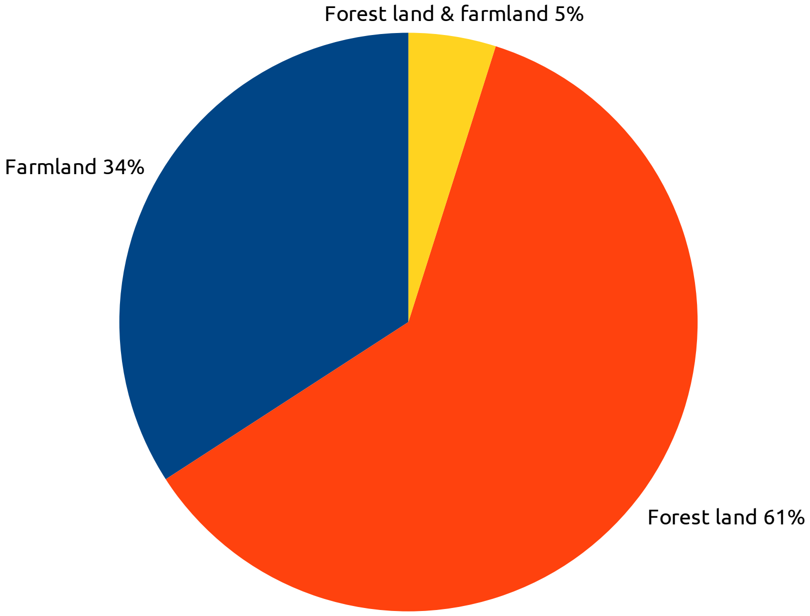

Figure 15: Target land uses.

3.1 Forest management for reduced soil emissions

3.1.1 Continuous-cover forestry

Organic soils specific measure, which can be, however, implemented also in forests with mineral soils. The measure is identified as potentially valuable in Finland and Latvia with ongoing research activities in Finland. The greenhouse gas balance impacts of the different variants of this method are currently being studied in Finland. First results are expected in 2020 or 2021. Specific emission factors may be developed (a Tier 2 method), or data may be utilized in modelling of soil emissions (a Tier 3 method). Activity data may be obtained from harvesting reports collected by forest authorities, or based on national forest inventories. Active management is required for long-term impact. Up to 1.5 million hectares can be subjected to this measure in Finland alone. Conformity with sustainability criteria is potentially high. Cost – benefit ratio is not available yet, first estimates may be available in 2021. The method has been included in national guidelines for good forest management, some demo sites exist and will be used as reference sites in this project. The method should be treated equally with conventional management in the revised support scheme that is under evaluation currently (Korkiakoski et al., 2019; M. Nieminen et al., 2018; P. 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 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.

Stand wise forest inventory data can be used to locate areas where the measure is implemented to obtain local level activity data. NFI in combination with stand wise inventory can be used to obtain national level 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 to verify growth; however scientific approval of this method needs to be developed at first.

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. Not estimated yet. Not estimated, negative effect can be associated with distribution of root rot and other forest pests negatively affecting resilience of ecosystems; however no scientific verification is done.

Quantitative impact also is not estimated yet. The measure can result in increased harvest costs in case of selective felling due to lower productivity and additional cost of salvage logging. Reduced cost for maintenance of drainage systems can be considered.

The measure is not supported by specific legal acts but can be applied voluntary by forest owner. Selective harvests of pine is mandatory in coastal areas; however peatlands are minor in this area in Latvia.

3.2 Forest products

3.2.1 Improved algorithms creating bucking instructions and laser scanning and image analysis technologies to improve output of assortments

Organic soils non-specific measure. The measure is identified as potentially valuable in Latvia. Impact of the measure can be evaluated comparing standard and adopted bucking methods. It is important to note that the advanced bucking methods still needs to be developed and, depending from complexity of the solution, it can be implemented using standard harvester PC without modifications, respectively bucking priorities are elaborated by external software or bucking instructions can be implemented in the harvester PC integrating laser scanning and image analysis, respectively actual stem characteristics are considered in bucking instructions.

More accurate data on stand characteristics are necessary to improve bucking instructions using simplified approach (planning according to already existing stand data). Impact assessment can be done using harvester production files and harvesting statistics. Additional removals in HWP takes place during the year of wood processing.

Quantitative impact at national level is not yet estimated. No interferences are found with sustainability criteria of forest management. The measure is not associated with additional costs at a forest management side; however, the methods for improvement of bucking instructions still have to be developed, respectively, significant investment in research and development are necessary.

Increased efficiency of wood processing will reduce outputs of solid biofuel in wood processing.

The measure is not supported in national policies; however, it is market driven activity and will be implemented by forest industry.

3.2.2 Increase efficiency of utilization of timber – less biofuel and pulpwood and more harvested wood products with long half-life period

Organic soils non-specific measure. The measure is identified as potentially valuable in Latvia. Scientific data on the biomass processing efficiency, data on investments and national statistics on HWP production can be used to estimate GHG emission reduction. No need to use LPIS to estimate GHG emission reduction. Certification and tracking of material flow can provide valuable information for impact assessment.

Additional removals in HWP takes place during the year of wood processing; however, a single investment in technologies contributes to additional removals in HWP continuously.

The implementation potential at national level is not yet evaluated. No interferences with sustainability criteria of forest management are identified. No cost – benefit estimates are done.

Increased efficiency of wood processing will reduce outputs energy products in wood processing, increasing demand from other sources.

The measure is not supported in national policies; however, as a market driven activity it will be implemented by forest industry to ensure competitiveness in developing wood market.

3.2.3 Introduction of low impact logging technologies to avoid formation of methane hotspots and distribution of root rot and to ensure forest regeneration

Organic soils specific measure; however, it is important also for increase of accessibility of forest resources areas with wet soils and during spring and autumn period when bearing capacity of soils significantly decreases. The measure is identified as potentially valuable in Latvia. The methods for evaluation of the potential impact of this measure on GHG emissions are not developed yet, as well as methods for the impact assessment of the replacement of harvesting technologies. Stand wise inventory has to be significantly improved by adding data characterizing soil bearing capacity, water regime and management history (location of strip-roads, extracted volumes), which are necessary to evaluate the potential impact of the measure. Big data has to be used to keep track of management history and site impact. Limitations due to regulations on private data protection have to be solved.

The measure has continuous impact on forest growth and soil GHG emissions; however, actual distribution of emission reduction during the forest rotation is not yet estimated.

Quantitative implementation potential in terms of GHG emission reduction is not yet estimated. According to different assumptions the demand for new type of tracked forwarders or wheeled forwarders with new type of excavator tracks is about 100-150 machines; the demand for compact-class forest machines can reach 50-100 machines depending from utilization rate (Kalēja et al., 2017; Lazdiņš & Petaja, 2016; A. Zimelis et al., 2016). The aim to reduce impact on soil conforms with the sustainability criteria in forestry.

Cost – benefit ratio in terms of GHG emission reduction is not estimated, the implementation of the measure is economically driven – in many cases low impact logging technologies at the same time is also economically more efficient choice. Utilization of low impact logging principles by implementation of new harvesting technologies will improve stability of roundwood and biofuel deliveries, especially in spring and autumn when soil bearing capacity becomes worse. Use of excavator tracks or tracked forwarders considerably increase amount of technically accessible harvesting residues which can be utilized in energy wood production contributing to energy sector.

The measure is not supported in national policies; but there is ongoing trend to use new types of tracks and compact class forest machines in harvesting (Agris Zimelis et al., 2018, 2019).

3.2.4 More efficient harvesting technologies to reduce timber damages

Organic soils non-specific measure. The measure is identified as potentially valuable in Latvia. Scientific data on reduction of production losses due to log damages with feed rollers and national statistics of HWP production from locally produced roundwood (Rottensteiner, 2010; Agris Zimelis, Kaleja, et al., 2017; Agris Zimelis, Lazdiņš, et al., 2017). No need to use LPIS to estimate GHG emission reduction. Harvest statistics and periodic monitoring at the end use sites is necessary for impact assessment.

Additional removals in HWP takes place during the year of wood processing. The implementation potential at national level is not yet evaluated; for some types of HWP it can have significant impact, e.g. in production of poles use of sensitive feed rollers reduces production losses by up to 30%.

No interferences with sustainability criteria of forest management are identified. The measure is not associated with additional costs at a forest management side and requires additional investments in harvesting machinery. Increased efficiency of wood processing will reduce outputs of solid biofuel in wood processing. Utilization of advantages of sensitive feed rollers requires improved professional skills from operators.

The measure is not supported in national policies, but use of low impact feed rollers is considered as an option in the harvesting service contracts by Joint stock company "Latvia's state forests".

3.3 Increasing productivity

3.3.1 Adaptation of drainage systems to optimal depth of groundwater and inflow to avoid CH_4 emissions and to reduce CO_2 emissions

Drained organic soils specific measure; however, it has impact on drained mineral soils too, especially on soil carbon stock. The measure is identified as potentially valuable in Latvia. The methods for evaluation of impact of this measure, as well as success of implementation, has to be developed. Stand wise inventory and drainage data needs to be supplemented with information on drainage status and projections of impact of the implemented measures on dynamics of groundwater level. High resolution based LiDAR data are necessary to make projections of the impact, as well as to determine where the measure can be efficient.

There are no reliable evidences on the impact of the measure; however, it should affect GHG emissions continuously. Additional measures, that needs to be implemented, is maintenance of drainage systems, particularly, during the forest regeneration or compensatory fertilization. Potential quantitative impact in Latvia is not estimated yet and scientifically proven data are not available.

No conformity issues with the sustainability criteria are known, especially because the measure is implemented in already drained forests and the measure increase resilience of forest ecosystems.

Cost – benefit ratio of the measure is not estimated. The measure is targeted to increase of resilience of forest ecosystems, it will also increase future deliveries of roundwood and solid biofuel contributing to energy sector and substitution in other industries.

The measure is not supported in national policies.

3.3.2 Application of mineral fertilizers (N, P, K) and reduction of rotation length

Organic soils non-specific measure; however, P and K containing fertilizers usually are more efficient in forests with organic soils. The measure is identified as potentially valuable in Latvia; however, it is also supported by 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). There are no models implemented to estimate impact of changes in forest management, therefore only short term impact is considered. NFI and stand wise forest inventory data are used to estimate carbon stock changes at local and national level.

National LPIS data and NFI do not provide information on application of fertilizers therefore reporting of forest fertilization at a stand wise level should be implemented. These data can be utilized for national (NFI) and local level (stand wise inventory) to report additional GHG removals. Projections of long term impact can be verified by application of remote sensing (vegetation indexes, LiDAR, radar) data.

Short term impact continues for 10-20 years; long term impact continues during the whole rotation, especially if it is associated with changes in management regime. No additional measures are necessary to ensure short term effect; long term effect requires following to good practice guidelines in thinning, timely regenerative felling and maintenance of drainage systems. Additional increment due to forest fertilization can reach **39 mill. tonnes CO_2 during 2 forest management cycles** if only short term impact not considering reduction of rotation period is applied. Replacement of species is also considered in calculation. This measure is alternative to application of wood ash.

Shortening of rotation period may be considered as non-conforming with the sustainability criteria; however, further studies are necessary to improve forest management to increase resilience of forest ecosystem. Management changes can also require changes in legislation of forest management to reduce threshold values for regenerative felling. Fertilization of poor soils may lead to increase of soil fertility and changes in ground vegetation to more fertile species. Fertilization cost is **160 € ha^{-1}**. Cost of CO_2 removals, if short term impact is considered, equals to **8 € ton^{-1} CO_2 eq.** (Bērziņa et al., 2018).

Fertilization increases N_2O emissions from soil. 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; however fuel consumption per produced unit would decrease (Okmanis et al., 2018; Petaja et al., 2018).

No support is considered for fertilization in national legislation; however, it is not restricted either.

3.3.3 Drainage and intensification of forest management on fertile wet organic soils

Naturally wet organic soils targeted measure; however, it has even bigger implementation potential in forests with wet mineral soils, especially on living and dead biomass carbon pool. Information on soil carbon pool and non-CO_2 emissions is not sufficient. The measure is identified as potentially valuable in Latvia. The impact of the measures can be identified and projected using forest growth model comparing forest growth rate on drained and wet soils representing different soil fertility classes. The information on fertile drained soils is limited, the information on wet soils is absent, only information on drained organic soils with limited nutritional supplies is available, therefore only carbon stock changes in living biomass is considered in calculation up to know (Lazdiņš & Lupiķis, 2019; Lupiķis, 2019). Tier 1 method can be applied for soil emission calculation (rewetted vs. drained soils). Ability to model carbon stock changes using existing models is limited therefore difference between growth curves on dry or drained soils is used. Ability to calculate difference in growth rate at a single stand level is limited by different initial conditions (groundwater level, nutritional regime, species composition).

Current stand wise inventory data contains sufficient spatial information, however, information on water regime (groundwater depth) and soil type is limited, therefore evaluation of the impact of the measure requires evaluation of local conditions. Information on actual nutritional regime (nitrogen index), water regime and stand composition needs to be elaborated at national level for stand wise inventory and NFI.

Duration of impact equals to the whole rotation; to ensure the proposed impact timely thinnings and regenerative felling should be done. Important measure is maintenance of drainage systems and restoration of drainage system after regenerative felling, as well as nutrient recycling using wood ash or mineral fertilizers.

Drainage on organic soils can be implemented in 150 kha area (forests on naturally wet nutrient-rich soils). Quantitative impact assessment is not yet done. The net impact of GHG emission reduction is not estimated yet and not considered in the existing forest growth and emission assessment models.

Drainage of wet soils can be considered as non-sustainable and with negative impact on biodiversity, but it depends from the initial conditions – usually limiting factor is not continuously high groundwater level, but periodic increase of groundwater level causing disease of roots and limiting growth of trees; therefore, drainage will not have significant impact on vegetation, but improve growth of trees. The remedial drainage (listed as another measure) can be alternative way for successful forest regeneration after clear-felling; therefore, this measure is actually contributing to retaining of biodiversity by proper forest regeneration conditions.

Cost of carbon stock changes is **3 € ton^{-1} CO_2** according to recent studies, the estimate takes in account discount rate of 5%. 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. Drainage of organic soils can also considerably decrease outputs of Hg into water bodies. There is ongoing research on this topic.

There is no support for the forest drainage to establish new systems.

3.3.4 Fertilization with wood ash instead of ditch network maintenance

Drained organic soils specific measure; however, it can have impact in forest with drained mineral soils too. The measure is identified as potentially valuable in Finland and Latvia; however, earlier studies in Latvia demonstrates considerable increase of risk of windthrow and root rot distribution if clearfellings are replaced by selective felling. Research on the impacts is on-going on in Finland. Activity data need to be collected; currently no information flow to the greenhouse gas inventory. In total 1.5 mill. ha of forests are suitable for this measure in Finland. No harmful impacts have been observed for ash fertilization in Finnish studies. The ground vegetation composition may change however, so sites with valuable ground vegetation features should not be treated.

Fertilization with wood ash instead of ditch network maintenance is accepted form of management in Finland. Is expected to be profitable and cost-effective for the forest owner (Ahtikoski & Hökkä, 2019; Hökkä et al., 2012; Huotari et al., 2015).

In Latvia no scientifically verified data exists to demonstrate impact of this measure The implementation of research trials is considered in the research program on improvement of growth conditions. Stand wise forest inventory data can be used to locate areas where the measure is implemented to obtain local level activity data. LPIS system has to be improved adding more information about forest parcels with forestry data – stand age, growing stock volume, species composition, etc. No data on impact of the measure, as well as on the implementation potential in Latvia exists up to now.

The measure is not associated with considerable changes in forest characteristics; however fertility of topsoil will increase resulting in possible changes in composition of ground vegetation. Cost – benefit ratio is not estimated yet. Cost of spreading of wood ash is up to **100 eur ha^{-1}**. Additional costs may raise due to poor soil bearing capacity, which can also be limiting factor for implementation of the measure. Implementation of the measure can create potential cost saving in energy sector due to more opportunities to utilize wood ash.

Implementation of this measure is not supported in Latvia.

3.3.5 Improvement of genetic properties and adaptiveness of planting material

Organic soils non-specific measure; however, breeding can be targeted on more resilient clones of trees more tolerant to conditions in drained or wet organic soils, e.g. higher tolerance to periodic flooding and secondary disturbances in weakened forest stands with organic soils. The measure is identified as potentially valuable in Latvia. Research results and earlier studies on the potential impact of breeding on forest growth can be used for assessment of the impact of the measure. Existing stand wise inventories need to be improved to provide spatial information on planting material used in forest regeneration as well as information on planting material applied in older artificially regenerated stands.

The impact of the measure is continuing during the whole rotation period and have continuous long lasting effect in dead wood and HWP pools. Continuous breeding and implementation of the breeding results creates cumulative effect during longer period because even better planting material is used in forest regeneration.

Potential impact of existing breeding programs at a national level is not estimated yet in Latvia. According to previous experience every next generation of improved material contributes to increase of growth rate by **15-20%** in comparison to previous generation of trees. Use of high quality breeding material is in line with the forest management sustainability criteria (Jansons, 2006, 2008).

Cost-benefit ratio is not estimated yet for the climate change mitigation effect. Investments into the breeding program are considered by the Joint stock company "Latvia state forests".

Increased biomass production potential creates additional deliveries of roundwood and solid biofuel to the market. Better stem quality and stand structure increases productivity and output of HWP.

Forest regeneration with improved planting material is not financially supported, however, it is requested in case of providing support for afforestation and forest regeneration after natural disturbances.

3.3.6 Intensification of management and reduction of rotation

The measure partially overlaps with support to pre-commercial thinning, but extends it with more significant changes in forest management. This is organic soils non-specific measure requiring special complex of the forest management measures adopted for organic soils. The measure is identified as potentially valuable in Latvia.

Forest growth models can be used to demonstrate removals of CO_2 in living biomass and dead wood under different management scenarios; however these models are limited by available historical background data, which might not properly reflect on changes of forest management. Contribution to other carbon pools except living biomass can be calculated using growth, mortality and harvesting projections. It is more complicated to evaluate impact of changes of tree dimensions (as dead wood) on decomposition rate (Zālītis & Jansons, 2009; Zālītis et al., 2017).

Verification of this measure is complicated, however information on forest management activities reported to stand wise forest inventories can be used for projections of impact of forest management intensity and monitor if forest owners are following to proposed management intensity. Remote sensing data are necessary to provide detailed information on management intensities and growth response. At a national level combination of data provided in stand wise inventory and NFI can be used to verify if large scale changes in forest management leads to increase of CO_2 removals

Duration of the measure is 40-60 years, according to duration of shortened rotation period. Proper thinnings, forest protection measures and timely implemented regenerative felling should be done. It is important to continue management leading to increase of carbon stock in following rotations, too. Quantitative assessment is not yet done. It is partly covered by other climate change mitigation measures. e.g. support to pre-commercial thinning, and can be considered as a framework measure integrating forest fertilization, regeneration and pre-commercial thinning.

Reduction of rotation length or species changes can be considered as non-conforming with the sustainability criteria; however, there are no research data proving any impact.

Cost-benefit ratio of significant changes in forest management methods is not yet estimated in Latvia. Higher yields and share of HWP will contribute to increase of deliveries of roundwood and solid biofuel.

Intensification of forest management is not supported as complex measure. Only pre-commercial thinning is supported by Rural Development Program. Forest management requirements do not permits reduction of rotation period, however, regenerative felling can be done according to threshold of diameter of trees.

3.3.7 Introduction of innovative soil scarification methods and improved planting material to reduce regeneration period

This is organic soils non-specific measure; however, it can be particularly efficient in forests with drained or wet organic and mineral soils, periodically and, especially during the regeneration period, suffering from exceeding amount of water. The measure is identified as potentially valuable in Latvia. Impact of this measure is not yet implemented in the forest growth models due to lack of long term observations based data and high uncertainty of available data, which are mainly based on "learning by doing" trials. However, the measure is pointed out in national research projects and information on early growth rates comparison will be soon available from national studies. Long term impact can be evaluated using conventional modelling approach. The long term impact of the measure depends from further forest management steps, particularly, from timely thinning and regenerative felling. Impact on other carbon pools can be extrapolated from growth model. Impact on soil GHG emissions needs to be evaluated (Dzerina et al., 2016).

Stand wise forest inventory and NFI can provide information on areas where this measure can contribute to additional CO_2 removals due to mounding at a local and national scale. The projections highly depends on early management and probabilities of different development scenarios. These probabilities needs to be developed to create projections at a national level. Short term impact, which can be relatively easily estimated just by assuming faster growth of planted trees is relatively small and do not have significant impact on carbon stock changes in a short term.

The measure has continuous impact during the lifetime of the regenerated forest stand. The impact of the measure depends from probability of timely tending, thinning and regenerative felling, as well as end use of extracted wood. 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.

Quantitative impact is not evaluated yet in Latvia. The implementation potential in Latvia is determined by area of **nutrient-rich organic forest soils (454 kha)**. It should be noted that in considerable areas implementation of the measure should be associated with replacement of dominant species during regeneration.

Implementation of this measure increase resilience and potential value of forests on nutrient-rich soils contributing to implementation of sustainability criteria associated with forest value.Mounding increase **soil scarification cost by 150-20 eur ha^{-1}**; however, it can also contribute to reduction of cost during early tending and pre-commercial thinning. Conventional management systems needs to be updated to utilize the potential of fertile forest soils more efficient. Management practices, e.g. remedial ditching should be introduced in wet soils to ensure high growth potential of the regenerated forests.

Additional increment and outputs of roundwood and forest biofuel will create input to energy sector and wood processing industry. Reduced risk of wind throws will make deliveries of biomass more predictable and will reduce cost of deliveries of roundwood and biofuel. Midterm impact of intensification of forest management might be associated with increase of low grade biomass (pulpwood, biofuel) from intermediate fellings; however, this needs to be evaluated further in line with different management alternatives.

This measure is not supported by government; however there is proposal to consider support for purchasing of planting machines in the Rural Development Program 2021-2030, which will boost application of mounding in forest regeneration. A single machine can plant about 200 ha per season; however, this number can be increased if the planting season is extended.

3.3.8 Maintenance of existing drainage systems after regenerative felling

This is drained organic and mineral soils specific measure, which is conventional alternative to 'Fertilization with wood ash instead of ditch network maintenance'. The measure is identified as potentially valuable in Latvia. Forest growth models comparing growth curves of naturally wet and drained forests comparing similar growth conditions (soil parent material) can be used to estimate climate change mitigation effect. Only living biomass is considered now. Existing models are not capable to estimate carbon stock changes in dead wood litter and soil, particularly in case of rewetting of previously drained soils. It is also not known how the rewetting affects decomposition of below ground biomass considering limited aeration of deeper soils layers. Soil GHG emissions are only considered using tier 1 methods and country specific emission factors for drained organic soils (Lazdiņš & Lupiķis, 2014; Lazdiņš, Lupiķis, et al., 2014; Lupiķis et al., 2014).

Existing NFI and stand wise inventory data needs to be improved and supplemented with data characterizing water regime. Currently available data are sufficient for rough national level estimates, but stand level projections needs improvement of the data characterizing conditions of drainage systems. Full scale implementation of the measure requires approximately 80 years and full effect will be reached in 2 rotations – 160-200 years. In case of shortening rotation the effect will be reached in shorter period of time. To ensure high growth rates forest stands needs to be properly regenerated, thinned and harvested in time. Maintenance of drainage systems is of the highest importance.

The average annual impact of the measure on **CO_2 removals is 1.2 tonnes CO_2 ha^{-1}** and the average impact during the rotation period is **99 tonnes CO_2 ha^{-1}**. The carbon stock change in dead wood and litter carbon pools is not considered in the calculation. The total GHG reduction potential, considering only living biomass, is **89 mill. tonnes CO_2 per rotation** (Petaja et al., 2018).

Maintenance of existing drainage systems considering rewetting of very poor soils can be considered as sustainable management practice; however, reduction of rotation length can be blamed as non-conforming to the sustainability criteria.

Investment costs are calculated using discount rate of 5% for 20 years period. Discounted cost of the GHG emission reduction at the end of this period is **5 € ton^{-1} CO_2** (Bērziņa et al., 2018). It is important to note that this measure ensures, to large extend, that the deliveries of roundwood and solid biofuel from forest lands is not decreasing, but remains the in the same level. Additional removals are accounted under the measure – purposeful forest regeneration. The measure is important to maintain fertility of drained croplands because the systems are connected. Deliveries of roundwood and biofuel are important to maintain wood industry and energy sector.

The measure is adopted according to Regulations of the Cabinet of Ministers No. 600 (30.09.2014) considering support to restoration of drainage systems in forests and farmlands. Support will be provided until 2020. Further support is not yet approved in regulations, but it is listed as climate change mitigation measures in biannual reports.

3.3.9 Pre-commercial thinning to improve species composition, increase growth rate and reduce rotation length

This is organic soils non-specific measure and have significant climate change mitigation potential in all forests. This is also a part of other measures, e.g. 'Intensification of management and reduction of rotation' and mandatory precondition to all productivity targeted measures. The measure is identified as potentially valuable in Latvia. Climate change mitigation impact (in living biomass) can be estimated using forest growth model AGM assuming additional relative increments in areas where thinning is done. The impact is estimated using forest growth model as a response to changes of basal area and change of dominant species. Stand wise forest inventory data can be used to locate areas where the measures are implemented to obtain local level activity data. NFI in combination with stand wise inventory can be used to obtain national level data. National LPIS system needs to be improved to provide accurate data on the stand basal area, tree height and dominant species. There is still considerable uncertainty in stand wise inventory resulting in poor accuracy of the estimates of carbon stock changes. Uncertainty at a local level is also affected by dependency from long term management measures.The direct impact on additional increment continues for 20 years after thinning; growing stock in 40-60 years old coniferous stands and research trials in Latvia is by 15-25% higher than in non-thinned stands. Long term impact depends from additional measures (commercial thinning, sanitary fellings, fertilization, maintenance of drainage systems, regenerative felling, forest regeneration method). There is no need for additional measures to ensure short term impact. The average impact of the measure is **1.4 tonnes CO_2 ha^{-1} yr^{-1} during the 15 years period**. Assuming that forest stands on drained organic soils are thinned according good practice guidelines, the additional increment due to forest thinning equals to **10 mill. tonnes CO_2 in 200 years period** (Bērziņa et al., 2018). This value is not including long term impact on carbon stock changes. The impact is partially already accessed by current management activities.

The measure is not associated with considerable changes in forest characteristics except changes in dominant species and reduction of areas of low valued deciduous tree species and pioneer species. This may be considered as negative impact on biodiversity.

Short term impact (due to additional increment after thinning) costs **8.6 € ton^{-1} CO_2** (Lazdiņš et al., 2015). 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 equals to 5% of the CO_2 output with biofuel and wood logs.

Pre-commercial thinning is supported by Rural development program, estimated support for 120000 ha of forest stands in private forests; organic soils are not highlighted additionally.

3.3.10 Recycling of wood ash in forest

The potential of the measure is identified as significant in Latvia, where it is proposed as drained organic and mineral soils specific measure (Okmanis et al., 2018; Okmanis, Lazdiņš, et al., 2015; Okmanis, Polmanis, et al., 2015). As a mixture with N containing fertilizers it can be used in mineral soils too.

Linear additional increment rate (15 m^3 ha^{-1} per treatment) are considered according to the treated area assuming that forest management is optimized to ensure the additional increment. There are no models implemented to estimate impact of changes in forest management, therefore only short term impact is considered. NFI and stand wise forest inventory data are used to estimate carbon stock changes at local and national level. Tier 1 is used to estimate non-CO_2 emissions.

National LPIS data and NFI do 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 for national (NFI) and local level (stand wise inventory) to report additional GHG removals. Projections of long term impact can be verified by application of remote sensing (vegetation indexes, LiDAR, radar) data.

Short term impact continues for 10-20 years; long term impact continues during the whole rotation, especially if it is associated with changes in management regime. No additional measures are necessary to ensure short term effect; 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) has to be planted instead of low quality stands. Additional increment due to forest fertilization can reach **8 mill. tonnes CO_2 during 2 forest management cycles** if only short term impact not considering reduction of rotation period is applied. Replacement of species is also considered in calculation. Drainage and recycling of wood ash in naturally wet organic soils would provide additional **5.3 mill tonnes CO_2 removals and reduction of CH_4 and N_2O emissions from soil**.

Shortening of rotation period may be considered as non-conforming with the criteria; management changes can also require changes in legislation of forest management to reduce final felling limits. Application of wood ash on of poor soils may lead to increase of soil fertility and changes in ground vegetation to more fertile species.

Fertilization **cost is 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)**. 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. Implementation of the measure might be limited by availability and quality of wood ash. Energy sector should adopt to quality demands of wood ash recycling.

No support is considered for fertilization wood ash in national legislation in Latvia.

3.3.11 Reconstruction of low valued forest stands

This is organic soils non-specific measure and have significant climate change mitigation potential in all forests, especially in private forests not managed properly or suffering from natural disturbances. The measure is identified as potentially valuable in Latvia. Forest growth models can be used to estimate additional CO_2 removals in living biomass and dead wood in comparison to current status. High uncertainty is associated with estimation of current status and growth potential. NFI data can be used for national scale verification of impact of the measure; stand wise inventory can be used to obtain stand level data; however, information about stands needs to be improved.

Up to 100 year considering the longest rotation period (for pine). Shorter rotations for other species (birch and spruce). Changes in rotation length are not considered in calculation. The additional CO_2 removals in living biomass during the rotation period is **100 tonnes CO_2 ha^{-1}**. The emission reduction potential according to the estimates in

Rural development program is **157 ktons CO_2 until 2030; however, it is not representing total climate** change mitigation potential of this measure, but represents impact of the proposed funding.

The measure conforms with the sustainability criteria. Additional costs, assuming that harvesting costs are covered by extracted wood, are **about 400 € ha^{-1}**, including forest regeneration cost, respectively, cost for emission reduction is **4 € tonne CO_2** of additional removals in living biomass. Other carbon pools are not considered. Other forest management costs are not considered as a part of conventional management practice. Considerable additional increment and outputs of roundwood and forest biofuel will create significant input to energy sector and wood processing industry.

Higher yields would increase fuel consumption in forest operations, which can reach 5% of the CO_2 output with biofuel and wood logs; however, fuel consumption per unit and production costs will decrease due to larger dimensions of trunks.

Support is considered in Rural Development Program for regeneration of **10000 ha of forests until 2030**.

3.3.12 Regeneration of forests after natural disturbances

This is organic soils non-specific measure and have significant climate change mitigation potential in all forest lands. The measure is identified as potentially valuable in Latvia. Forest growth models can be used to estimate additional CO_2 removals in living biomass and dead wood in comparison to alternative scenario – natural regeneration. Stand wise inventory and NFI can be used to monitor the impact on living biomass and dead wood carbon pools. Soil is highly dependant from initial situation and changes are more complicated to predict. Up to 100 year considering the longest rotation period (for pine). Shorter rotations for other species (birch and spruce). Changes in rotation length are not considered in calculation.

The additional CO_2 removals in living biomass during the **rotation period is 100 tonnes CO_2 ha^{-1}**. No country wide assessment is done, however, the implementation scale could be **3000 ha yr^{-1}**; respectively, investments in 1 year would result in a 100 years in **additional 0.3 mill. tons CO_2 removals**. A part of this measure is already accounted under potential impact of other measures; existing forest regeneration practice in state forests is already ensuring implementation of this measure, therefore only private forest can contribute to additional CO_2 removals; state forests can basically only maintain existing removal potential.

The measure conforms with the sustainability criteria. Additional **costs are about 400 € ha^{-1}**, including forest regeneration cost, respectively, cost for emission reduction is **4 € ton CO_2** of additional removals in living biomass. Other carbon pools are not considered. Other forest management costs are not considered, as being a part of conventional management practice (Bērziņa et al., 2018).

Considerable additional increment and outputs of roundwood and forest biofuel will create significant input to energy sector and wood processing industry. Higher yields would increase fuel consumption in forest operations, which can reach 5% of the CO_2 output with biofuel and wood logs, however, this increase will be compensated by smaller fuel consumption of fuel per unit and by additional deliveries of biofuel and HWP.

Support to this measure is considered in Rural Development Program, the proposed implementation area is shared with reconstruction of poor quality stands, respectively, **10000 ha for both measures until 2030**.

3.3.13 Remedial ditching to enhance regeneration of forests on wet soils after regenerative felling

This is wet mineral and organic soils specific measure and have significant climate change mitigation potential in managed forests. The measure is identified as potentially valuable in Latvia; however, the potential role of remedial ditching is studied also in Sweden and Finland (Lundin, 1994; Paavilainen & Päivänen, 1995; Trettin et al., 1996).

The impact of the measure is not validated yet in Latvia and experimental data are missing. Stand wise inventory should be supplemented with information on water regime in forest stands, particularly, on sub-stand level demonstrating areas with exceeding surface water in predominantly dry sites. For rough national level estimates NFI and stand wise inventory can be used; however considerable uncertainty can be introduced due to limited information on water regime.

Impact of the measure continues during the whole rotation, **80 years in average or 70-100 years depending from dominant tree species**. Shorter rotation period can be considered. Full effect will be reached in **2 rotations – 160-200 years**. In case of shortening rotation the effect will be reached in shorter period of time. To ensure high growth rates forest stands needs to be properly regenerated, thinned and harvested in time. Drainage systems should be restored after regenerative felling.

The potential impact of the measure is not estimated yet in Latvia. Total area of forests on naturally wet nutrient-rich organic soils – 150 kha. This measure can be implemented instead of permanent drainage. Remedial ditching ensures successful regeneration of forests on naturally wet soils, therefore this measure is also contributing to retaining of biodiversity of forests on wet soils. Replacement of low value species may be considered as negatively affecting biodiversity.

Cost benefit ratio of this measure is not estimated yet. This measure ensures that the deliveries of roundwood and solid biofuel from forest lands is not decreasing, but remains the same or even increases if forest breeding effect is considered and rotation period is shortened, where possible. Wood ash spreading and fertilization can considerably increase removals and reduce GHG emissions from soil during the forest regeneration period. The measure is important to maintain deliveries of roundwood and biofuel in long term.

The measure is not supported in national legislation.

3.3.14 Rewetting of low valued drained forests with limited growth potential

The measure is identified as potentially valuable in Latvia. This is nutrient-poor organic soils specific measure and can have certain climate change mitigation potential in managed forests; however, no scientific evidences of the impact of this measure are found in Latvia. There are no emissions factors which could be used to compare GHG emissions from drained and rewetted soils. According to available data net GHG emissions from drained nutrient-poor organic soils in forest soils are negative, respectively, positive impact of rewetting on GHG emissions (reduction of emissions) cannot be verified (Lazdiņš, Butlers, et al., 2014; Lazdiņš, Lupiķis, et al., 2014). Changes in living and dead wood carbon pool can be calculated using growth models.

Stand wise inventory and NFI data can be used to identify areas where the measure can be implemented. However, data on water regime and potentially affected areas in case of rewetting needs to be improved.

The measure has continuous impact during the lifetime of forest stand can be considered in forest soil. A generation of trees for carbon stock in living and dead wood. No measures are necessary to maintain the effect. Quantitative assessment of the measure is not done. **Area of forest on drained nutrient-poor poor organic soil is 20 kha.**

The measure conforms with the sustainability criteria, because of returning to natural state, however absolute estimates of the GHG emissions' reduction may be negative in rewetted forests.

No cost - benefit estimation is done in Latvia. Considerable additional costs may be necessity to maintain productivity of surrounding forest stands.

Rewetting of forest on nutrients-poor soils can result in reduction of HWP and biofuel output from forest lands. There are evidences of negative impact of rewetting on Hg outputs from rewetted soils, which still needs to be estimated (Eklöf et al., 2014; Larmola et al., 2010).

No support is considered in national policies; however there are plenty of LIFE program project contributing to rewetting of forest lands.

3.3.15 Use of improved planting material in forest regeneration utilizing existing achievements of forest breeding

Organic soils non-specific measure, which can be however targeted to organic soils by selection of genetic material more suitable to organic soils. The measure is identified as potentially valuable in Latvia. The impact can be estimated using forest growth models assuming additional relative increments in areas where genetically 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. NFI in combination with stand wise inventory can be used to obtain national level data. National LPIS system needs to be improved to keep track of areas where the measures are implemented.

Continuous measure, a single cycle for all forests would take up to 200 years (the longest rotation for pine); however the duration can be considerably reduced by shortening of rotation period. Additional measures which needs to be implemented are early tending, thinning and forest protection. Where necessary nutritional regime needs to be improved and areas suffering from exceeding surface water needs to be drained. Regenerative feeling should be done timely and next rotation should also be regenerated with improved planting material Assuming that implementation of the measure in all forests with ameliorated organic soil without management restrictions (0.4 mill. ha) and potentially optimal growth conditions, additional increment would equal to 129 mill. tonnes CO_2 (0.2 mill. tons yr^{-1}) removals. It should be noted that continues implementation of the measure would result in considerably higher rate of removals because several rotations of trees can be grown during 200 years period.

Output of roundwood would reach 20 mill. m^3, respectively about **10 mill. tonnes CO_2 of additional removals in HWP and about 12 mill. tonnes CO_2 an a biofuel contributing to replacement effect**. Contribution to other carbon pools can't be easily determined. Amelioration of remaining naturally wet organic soils in forests would double this effect; however, the impact on soil is not estimated.

Implementation of the measure is associated with increase of share of artificial forest regeneration to 100% in forests with organic soils, drainage of areas, where exceeding surface water limits growth of trees, and fertilization of poor soils, where additional increment is limited by nutrient shortage. This may be considered as negative impact on biodiversity.

Additional costs in current prices is about 450 eur 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 eur ton^{-1} CO_2**.

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). Research on this topic continues within the scope of Forest adaptation research program funded by Joint stock company "Latvia state forests".

There is general remark in national forest policy in Latvia that forest management should ensure that forest value is no decreasing, however there is no direct support to forest regeneration. The proposal for changes of in regulation of Cabinet of Ministers on harvesting of trees in forest lands includes remark that artificial regeneration is necessary in areas harvested by diameter.

3.4 Land use changes

3.4.1 Afforestation of farmlands on organic soils

Organic soils specific measure, which can be targeted to mineral soils; however, the most of the effect can be reached in areas with organic soils. The measure is identified as potentially valuable in Latvia and Finland. There is significant implementation potential in other project partner countries.

Forest growth model can be used to estimate carbon stock changes in living and dead biomass, as well as in HWP. Values typical for the highest fertility classes can be used in calculation; however, the afforestation period depends from quality of soil preparation, planting material and early tending. The highest uncertainty of the impact of afforestation on GHG emissions is characteristic for the first 2 decades after afforestation. Tier 2 methods can be used to estimate impact on soil carbon stock change and GHG emissions. The net GHG reduction potential in case of 70 years long rotation is **1855 tons CO_2 eq ha^{-1} (26 tonnes CO_2 ha^{-1} yr^{-1})**. The net GHG reduction potential in case of 40 years long rotation is **1218 tonnes CO_2 eq ha^{-1} (30 tonnes CO_2 ha^{-1} yr^{-1})**. Actual GHG emission reduction potential may be about twice smaller because the GHG emissions from soil in cropland in grassland can be overestimated in Temperate climate zone.

Marginal, low-valued grassland and cropland on mineral soil where afforestation is permitted according to national and local regulations. Measure has long term impact; for conventional management systems for living and dead wood, litter and HWP it is 71-91 years according to the age based rotation lengths, for intensified plantation forest scenario it is 40-50 years. Impact on soil depends from carbon stock in organic soil, respectively it depends from carbon stock in soil at steady state and difference in decomposition rate. Two alternatives are evaluated in the project – intensified and extensified coniferous forests. The area of organic soils considered in the calculation is **152 kha**. Use of conventional management systems for spruce or pine would lead to increase of CO_2 removals and reduction of GHG emissions by **79 mill. tons CO_2** in all carbon pools during 20 years period. Intensified management and shortening of rotation would lead to **90 mill. tons CO_2** removals during 20 years period. It should be noted that GHG emissions from soil in cropland and grassland may be overestimated now, therefore the emission reduction will be smaller. GHG emissions from soil in nutrient-rich organic soils in forest land can also be smaller than the estimated emission rates, which will also affect GHG emission reduction rate.

Afforestation is restoration on ecosystem on deforested lands and nutrient-rich bogs and in spite of potentially negative impact of species closely associated with artificial landscapes (cropland and grassland) afforestation contributes to formation of semi-natural forest land dominant ecosystems typical for Latvia. Efficient use of abandoned farmlands which do not produce any added value contributes to social and economic sustainability.

Cost of GHG emission reduction considering 20 years calculation period and 5% discount rate in case of extensive management is **6 € ton^{-1} CO_2**. Total investments in both cases in current prices are **264-282 mill. €** depending from selected scenario (**1740-1860 € ha^{-1}**). Cost of emission reduction might change depending from the actual emissions from soil in cropland, grassland and forest land (Bērziņa et al., 2018).

Additional increment and outputs of roundwood and forest biofuel will create input to energy sector and wood processing industry. Wood ash can be utilized in afforested organic soils. Afforestation of large areas of organic soils will affect farm production potential, however, the most of organic soils are nutrient-poor and extensively utilized.

There is no dedicated support for afforestation of organic soils in Finland and in Latvia; however it is not forbidden and organic soils can be afforested within the scope of climate change mitigation actions of Rural development program.

3.4.2 Conversion of cropland to pastures or grassland for fodder production

Organic soils specific measure. The measure is identified as potentially valuable in Latvia and Finland. There is also significant implementation potential in other project partner countries.

In Latvia groundwater level and temperature sensitive emission factors or averaged emission factors for cropland and grassland. N input data for calculation of impact on N_2O emissions in agriculture sector. Information on organic soils, N and C input with plant residues and organic waste needs to be updated and stored in LPIS system.

The measure has continuous impact equal to time necessary to decompose exceeding organic matter in soil. In long term difference between both systems is reducing, because in both cases exceeding organic matter will be decomposed at some point and the difference is determined by N_2O and CH_4 emissions.

The implementation potential in Latvia is about **8.5 tonnes CO_2 eq. ha^{-1}** both in agriculture and LULUCF sector. About **677 ktons CO_2 eq yr^{-1} if all organic soils in cropland are transferred to grassland in Latvia.** However this impact can be overestimated due to decomposition of organic matter not represented by soil maps or overestimated GHG emissions from cropland. **The measure interfere with afforestation of organic soils providing significantly higher mitigation effect**.

Increase of area or grassland and abandonment of cropland conforms to sustainability criteria.

The measure is not associated with additional cost, however income of farmers should be compensated. The measure reduces agriculture production potential; however, due to reduction of N_2O emissions provides opportunity to retain management activities in other sectors.

In Latvia indirect governmental support to greening activities – abandonment of certain area of croplands affecting to some extend organic soils (Ministry of Agriculture, 2018). In Finland there are different environmental payments favouring perennial cropping, which indirectly supports conversion of cropland to grassland.

3.4.3 Conversion of wet grasslands into woody paludicultures for HWP and biofuel production

Organic soils specific measure; however it can be implemented in areas with mineral soils too. The measure is identified as potentially valuable in Latvia.

Impact of the measure cannot be estimated with sufficient accuracy using currently available knowledge. Data for calculation of CO_2 removals in living biomass and other carbon pools in afforested paludicultures are missing; however, growth and mortality curves of forests on naturally wet mineral and organic soils can be used. Depending from projected soil nutritional and water regime, the most appropriate fertility class can be selected for growth projections. Uncertainty of the estimates is increased by high risk of natural disturbances (e.g. floods resulting in disease of the trees due to asphyxia or secondary pest invasions). There are no data available for evaluation of impact on soils GHG emissions from soil.

Existing LPIS and NFI data contains insufficient information on soil type, depreciation of drainage systems, as well as water and nutritional regime in grasslands; therefore national scale evaluation of the implementation potential is not possible. Similarly, implementation at local scale requires evaluation of every case individually. LPIS and NFI data need to be supplemented with information on depreciation of drainage systems, dynamic of groundwater level and nutritional status. Nationally and locally applicable tools for evaluation of impact of the changes of drainage systems needs to be developed to improve planning of establishment of paludicultures (e.g. to identify areas where forest growth is theoretically possible after complete deterioration of drainage systems).

Duration of the impact of the measure is at least one full rotation of trees; further reduction or increase of GHG emissions depends from management practices applied to the next generation of trees. Impact on soil GHG emissions is continuous, however the "sign" of the impact and the scale is not yet evaluated. There is significant probability that rewetting (if it is not already done) can increase soil GHG emissions.

Quantitative impact of this measure is not yet estimated in Latvia due to lack of reliable activity data and soil emission factors.

Forested wetlands creates valuable habitats for different species and contributes to restoration of vegetation typical for natural wetlands on nutrient-rich soils. Therefore the measure can't be blamed for non-conformity with the sustainability criteria. However, due to long implementation period (40-60 years until regenerative felling) production of goods in such paludicultures can be considered as harmful to environment and projections of HWP output and replacement effect in energy sector can be overestimated.

Costs of the measure is not estimated yet. Considering the forest regeneration costs, establishment of woody paludiculture can cost about **2000 €, ha^{-1} considering only forest regeneration costs**.

Woody paludicultures can become a considerable source of biofuel and roundwood for HWP production, however high production costs (low soil bearing capacity and small volume of trees) makes it less competitive in comparison to other sources of biomass.

The measure is not supported in national policies; however, the measure can be implemented within the scope of afforestation activity.

3.4.4 Intensive cultivated SRF in nutrient rich organic soils

Primarily nutrient rich mineral soils targeted measures, however can be implemented in organic soils too. The significant climate change mitigation potential of this measure is identified in Latvia. Considering area of organic soils in cropland, there is also significant implementation potential in other project partner countries.

Growth models for SRF and productivity models for SRC for estimation of removals of CO_2 in living biomass and further substitution effect and contribution to removals in HWP. Soil carbon stock changes may be estimated using emission factors; however, knowledge base for application of these factors, as well as information of carbon input with above and below-ground litter is insufficient. Inputs with wastewater sludge should be considered. Soil carbon stock changes may have considerable uncertainty at a local scale due to different initial conditions. Removals of CO_2 in living biomass in SRC depends from application of fertilizer and management of the crops. In SRF this uncertainty is less critical. however impact of the management is more significant in comparison to conventional afforestation or plantation forests.

Current LPIS systems are sufficient to provide country wide estimates. NFI may has too long period between 2 measurement cycles resulting in very high uncertainty in country wide SRC estimates. LPIS should be updated with information on additional measures, particularly on fertilization and harvesting of SRC. Remote data e.g. vegetation indexes and SAR data can be utilized to improve accuracy of evaluation of growth rate of SRC and SRF.

SRF and SRC has continuous impact which is ensured by implementation of breeding results and planting of new clones (after 2-3 rotations in SRF and 4-5 rotations in SRC). Majority of the additional CO_2 removals occurs during 20-25 years after planting, during the following 20-25 years the most of accumulation of carbon took place in soil due to decomposition of dead wood. In SRC majority of carbon stock changes accounted in LULUCF sector takes place during 5-10 years due to removals in living biomass and soil. During the following decades SRC contributes to substitution of fossil fuels. Establishment of **SRF in 100 kha area** would contribute to increase of CO_2 removals by **29 mill. tonnes CO_2 in all carbon pools 20 years period**. Establishment of **SRC in 30 kha** would lead to **2 mill. tonnes CO_2 removals during 20 years period in LULUCF sector**. Additional climate change mitigation effect is ensured by substantiation of fossil fuels. The total additional CO_2 removals in LULUCF sector and substitution effect **in energy sector from 30 kha of SRC in 20 years would reach 7.2 mill. tonnes CO_2**. Transition losses and GHG emissions due to incineration of biomass are considered in calculation. Alternative fuel used in calculation is natural gas. Impact on GHG emission accounting in waste sector is not accounted.

There are no evidences of negative impact of SRF and SRC on biodiversity; however there are complains about using genetically similar material in large areas, which increase risk of disturbances, e.g. spreading of pests or frost damages; therefore genetic diversity of clones should be considered and continuous improvement of the industrial clones should be ensured.

Cost of additional CO_2 removals in SRF is **17 € ton^{-1} CO_2**, if 20 years calculation period and 5% discount rate is considered. Cost of additional CO_2 removals in LULUCF sector in SRC is 46 €; however, if substitution effect is considered, SRC becomes on of the most efficient climate change mitigation measure. SRC and SRF have huge substitution potential in energy sector, pulp and paper production. SRC can also significantly reduce GHG emissions in waste sector by utilization of wastewater sludge and other organic residues. Per area payment is retained for SRC if the rotation period do not exceed 5 years, no support is considered for SRF; however, SRF can be established as plantation forests and owners of the plantation can save on property tax. All taxes has to be paid for SRF (Lazdiņš, 2018).

3.4.5 Rewetting of grassland – conversion to wetlands, to avoid CO_2 emissions

Organic soils targeted measure, which is identified as potentially valuable in Latvia. However, emission factors characterizing impact of the measure are not elaborated and verified in different growth conditions.

Additional management categories have to be introduced in LPIS system to report rewetting; regularly updated high resolution terrain data are necessary to evaluate changes in water regime in rewetted areas.

The measure should have continuous impact; no supplementary measures are necessity, however, removal of topsoil may be necessary according to study results in Germany (Tiemeyer, 2016).

Quantitative impact of the measure is not estimated in Latvia.

Abandonment of farmland fully conforms with sustainability criteria set in national legislation.

Cost – benefit ratio not estimated yet. Transfer of production may require additional farmland areas and will result in increase of GHG emissions from wetlands, which may be critical for implementation of 2030 targets in LULUCF sector.

Support is considered for nature conservation areas, however it doesn't relates to climate change mitigation targets.

3.5 Management of farmlands

3.5.1 Adaptation of drainage systems to optimal depth of groundwater and outflows to avoid CH_4 emissions and to reduce CO_2 and DOC emissions

Organic soils targeted measure; however the most significant impact can be, probably, reached in areas with semi-hydromorphic soils suffering from exceeding water periodically. The measure is identified as potentially valuable in Latvia. However, the evaluation of the implementation potential of this measure is in early development stages. No methodologies are elaborated to estimate potential impact of the measure. Information on drainage systems needs to be updated so that it reflects implementation of the measure and integrity of implemented measures and GHG emissions.

Duration of the impact equals to period of implementation of the measure and life-time of drainage systems.

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.

No support is implemented at national level.

3.5.2 Adjust fertilizer application rates and timing in croplands to reduce N_2O emissions

Organic soils non-specific measure, which can be implemented in all kind of soils with similar efficiency. The measure is identified as potentially valuable in Latvia.

Linear models estimating N_2O emissions due to fertilizers application can be used to estimate impact of the implemented measure. LPIS system needs to be upgraded to collect production related information, e.g. field level data on application of fertilizers and production.

Duration of the impact equals to period of implementation of the measure. Cost – benefit ration is not estimated yet. No adverse impact on biodiversity indicators is known. The measure have synergies with strategies aimed at reduction of NH_4 emissions from cropland.

Support for investments and application practices reducing use of fertilizers (Ministry of Agriculture, 2018; Ministry of Environmental Protection and Regional Development, 2019b).

3.5.3 Application of nitrification inhibitors to reduce N_4O emissions

Organic soils non-specific measure, which can be implemented in all kind of soils with similar efficiency. The measure is identified as potentially valuable in Latvia. The climate change mitigation effect of this measure reflects in agriculture sector, where emissions due to application of N containing fertilizers are reported.

Linear models for calculation of N_2O emissions can be used to evaluate impact of this measure. LPIS system needs to be upgraded to collect fertilizers and inhibitors application related information. Duration of the impact equals to period of implementation of the measure. Cost – benefit ratio is not estimated yet; however, the measure is evaluated within the scope of studies targeted at agriculture sector (Latvijas Lauksaimniecības universitāte, 2018). No adverse impacts known with biodiversity indicators. No interferences or synergies with other sectors are identified.

No support considered in Latvia in national policies; however, research is going on to implement this measure at later stages into the Rural development programme.

3.5.4 Buffer zones alongside to drainage systems to compensate CO_2 emissions, to reduce nutrients leaching and DOC emissions

Drained soils targeted measure; the most significant impact can be, probably, reached in areas with semi-hydromorphic and drained mineral soils. The measure is identified as potentially valuable in Latvia.

Climate change mitigation effect can be estimated using biomass expansion factors and growth models for calculation of carbon stock changes. However application of the methodologies elaborated for forest lands may be very uncertain in buffer zones, particularly because of utilization of productive hybrids and varieties of trees and shrubs in buffer zones.

LPIS has to be updated to ensure reporting of information on establishment and management of buffer zones, as well as to report utilization of biomass. Remote sensing based methods are necessary to monitor development of buffer zones.

Duration of the impact depends from life-time of buffer zone. Further removals can be ensured by application of more productive crops. According to preliminary assessment the net GHG emission reduction potential **in Latvia is 0.75 mill. tons CO_2 yr^{-1}**. Organic soils are not separated in the assessment. Following to proportion of the organic soils impact of areas on organic soils can be **10-15%**. Cost – benefit ratio of the measure is not estimated yet.

Buffer zones ensures increase of biologic value of farmlands and contributes to reduction of eutrophication of inland water bodies and Baltic sea. Buffer zones can become significant source of deliveries of biofuel. Buffer zones are also known for efficient utilization of leaching nutrients in cropland.

No support is implemented at national level in Latvia.

3.5.5 Increase of use of legumes to reduce N_2O emissions

Organic soils non-specific measure, which can be implemented in all kind of soils with similar efficiency. The measure is identified as potentially valuable in Latvia. The most of the climate change mitigation effect of this measure reflects in agriculture sector, where emissions due to application of N containing fertilizers are reported.

Biomass expansion factors for soil carbon input in comparison to conventional crop rotations can be used to estimate climate change mitigation effect; GHG emission factors have to be elaborated for calculation of impact on N_2O emissions. LPIS systems contains sufficient information on crops, however needs to be improved to report yields and soil biomass inputs (Bērziņa et al., 2018). Remote sensing methods has to be developed to ensure correct accounting of biomass input into soil.

Duration of impact equals to period of production of legumes. Cost – benefit ratio is not estimated yet. No adverse impacts on biodiversity indicators are known. The measure has synergy with strategies aimed at reduction of NH_4 emissions from cropland.

National policies considers per area payments for protein crops, no dedicated support for organic soils (Ministry of Agriculture, 2018).

3.5.6 Introduction of agroforestry systems to increase carbon storage

Organic soils non-specific measure, which can be implemented in all kind of soils; however the impact is considerably bigger in areas with organic soils. The measure is identified as potentially valuable in Latvia.

The methodologies for estimation of the climate change mitigation effect are not yet developed. Growth models and biomass equations can be used to estimate growth rate. Multiple research are covering this issue (Bardule et al., 2016; Lazdiņa, Krīgere, et al., 2019; Lazdiņa, Neimane, et al., 2019; Lazdiņš et al., 2019). LPIS has to be updated with new management categories and production rates, including utilization of crops. Duration of the measure equals to continuation of management of agroforestry crops, production of farm crops and wood products. In large scale it is similar to the impact of afforestation. Implementation potential in Latvia is not estimated yet. No adverse impact to biodiversity indicators are known; however the measure contributes to increase of HWP and energy wood production. Cost – benefit ratio of the measure is not estimated yet. No support considered in national policies.

3.5.7 Non-woody energy crops, e.g. reed canary grass, in cropland and grassland

Semi-hydromorphic and organic soils targeted measure; however the impact is considerably bigger in areas with organic soils in cropland due to reduction of GHG emissions from soil. The measure is identified as potentially valuable in Latvia; however, practical implementation of the measure takes place in Finland and Estonia. No state support for the measure is considered in these countries.

The mitigation effect can be estimated by calculation of GHG emission reduction due to replacement of fossil fuel and carbon input into soil using biomass prediction models. Limited data are available on GHG emissions from soil under different management regimes. Several studies on this topic are implemented in Estonia (J. O. Salm, 2012; J.-O. Salm et al., 2009, 2012). LPIS in Latvia should integrate data on biofuel production and use, as well as yields and harvesting methods. The measure has continuous impact, until management practise is not changed. However, crop rotation needs to be considered to avoid deterioration of growth conditions. Cost – benefit ratio is not estimated yet, depends from biofuel demand in energy sector, actual impact on GHG emissions and area of suitable lands. No negative impact on biodiversity indicators are known. The measure have synergy with the energy sector target to increase renewable energy production due to possibility to increase share of renewable energy sources.

No support, except area payments for any kind of crops, is considered in Latvia.

3.5.8 Optimize grassland management (species introduction, increase of lifespan of grasslands, increase of productivity)

Organic soils non-specific measure; which can be implemented on all kinds of soil. Organic soils may need specific treatment to ensure resilience and reduction of GHG emissions. The measure is identified as potentially valuable in Finland and Latvia.

In Latvia no methodologies for evaluation of the climate change mitigation effect are elaborated; hence, there are also no guidelines available for farmers to implement climate change mitigation management practices in grasslands. LPIS in Latvia has to be updated to provide information on climate change mitigation measures and yields demonstrating soil carbon input. Duration of the impact equals to period of implementation of the measure. Implementation potential in Latvia is not estimated yet. Conformity estimates with sustainability criteria are not done. Cost – benefit ratio can be determined after development of climate change mitigation targeted strategies for grassland management. No interferences or synergies with other sectors known.

No support is implemented at national level in Latvia. In Finland. this measure is supported by environmental payment for perennial grasslands in areas with organic soil.

3.5.9 Reduced tillage to avoid GHG emissions and carbon losses due to wind erosion

Organic soils non-specific measure; which can be implemented on all kinds of soil. The measure is identified as potentially valuable in Finland and Latvia.

In Latvia methodologies for assessment of impact of the measure are not developed yet. Emission factors, particularly on the transformation period to reach equilibrium level needs to be developed. Information on distribution of organic soils have to be improved, as well as data on tillage practice. The measure has continuous impact, as soon as management practice is not reverted to conventional methods. Cost – benefit ratio is not estimated yet. The measure conforms with sustainability criteria. No interferences or synergies found with other sectors, reduced tillage may increase chemical consumption in agriculture.

In Latvia the measure is not supported due to limited knowledge about impact of the measure of GHG emissions. In Finland the measure is supported by environmental payments – reduced tillage is accepted in the area of "winter-time vegetation cover" together with no-till, spring tillage and green vegetation cover.

3.6 Risk management

3.6.1 Avoiding degradation of natural surface water flows during thinning and regenerative felling

Organic soils non-specific measure, which can be implemented on all kind of soils; however the most significant impact can be reached in forests with wet and drained soils. The measure is identified as potentially valuable in Latvia.

Inter-stand variations of growth conditions can be used to evaluate potential impact on growing stock, however scientific verification of impact of forest machines (thinning and final felling) is not yet done. Impact on soil GHG emissions is not yet estimated.

Existing LPIS (stand wise inventory) has to be upgraded by inclusion of terrain, soil texture, groundwater level and water stream maps. Recommendations for management of forest to avoid adverse impact on water regime needs to be developed and verified in commercial scale. Harvester and forwarder data (Rossit et al., 2019) can be used to monitor potential impact of forest machinery at a national scale; however, the methodology still needs to be developed.

The measure has continuous impact, recommendations on forest management aimed at maintenance of optimal water regime ha to be used to avoid deterioration of water regime in future. Quantitative impact is not estimated yet and scientifically proven data are not available.

No biodiversity related issues are known, especially because implementation of the measure will increase resilience of forest ecosystems.

Information of the potential GHG emission reduction is not estimated and the cost-benefit ratio can't be estimated. The measure is targeted to increase of resilience of forest ecosystems, respectively it will increase future deliveries of roundwood and solid biofuel contributing to energy sector and substitution in other industries.

The measure is not supported in national policies; however, there are restrictions and recommendations for forest operations, e.g. rut depth, harvesting directions etc.

3.6.2 Elimination of hotspots of methane emissions – establishment of shallow ditch network to ensure aeration of topsoil layer

Organic soils specific measure, which can be implemented on all kind of drained and wet organic soils. The measure is identified as potentially valuable in Latvia.

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 due to local improvement of growth conditions. Impact on GHG emissions from soil cannot be verified using available data, particularly balance between additional CO_2 emissions and removals and CH_4 emissions. 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 (Melniks et al., 2019).

Existing LPIS system needs to be improved and supplied with maps characterizing "wetness", respectively, information necessary to identify hotspots of CH_4 emissions. The methodologies for elaboration of such maps is developed and verified in Latvia, however not yet fully implemented due to incomplete information on drainage ditches. Information on CH_4 emissions depending from water regime in predominantly dry soils needs to be elaborated. Therefore currently only additional CO_2 removals in living biomass can be estimated.

The measure suppose to have continuous duration limited only by global changes. Quantitative potential impact of the measure in Latvia is not yet evaluated.

Digging of 30-40 cm deep ditches in forest is in line with national regulations. Negative impact on certain species which needs wet conditions can be considered; however, the measure do not consider expansion of conventional drainage systems, but is aimed at improvement of growth conditions within a stand, therefore the stand type will not be changed after implementation of the measure.

Cost benefit ratio is not yet estimated. Implementation of the measure will contribute to increase of deliveries of roundwood and biofuel, reduction of costs of forest regeneration and harvesting (due to increase of soil bearing capacity). Implementation of the measure can boost diversification of forest management practices and more active utilization of excavators and mounding technology in forest regeneration, therefore this measure is closely related to the climate change mitigation measure aimed at improvement of soil scarification methods.

The measure is not supported in national policies; however, considering synergies with CH_4 and Hg outputs reduction related policies, this measure, just like maintenance and establishment of drainage systems in forest lands have significant implementation potential.

3.6.3 Fire prevention – mineralized belts, early warning systems, better equipped fire safety departments

Organic soils non-specific measure, which can be implemented on all kind of soils; however the most significant impact can be reached in forests with organic and dry mineral soils. The measure is identified as potentially valuable in Latvia.

Methods for quantitative assessment are not developed yet, especially, because it is complicated to predict amount of soil organic matter incinerated during forest fires, especially in unmanaged forests with considerable seasonal variations of groundwater level and higher concentration of dead wood. Local level assessment should be based on national level estimates. Existing

LPIS can be used to estimate risk of forest fires, however, impact of implemented measures cannot be easily verified, e.g. comparison of area of forest fire under current conditions and alternative scenario (no fire prevention system is used). It is also important to avoid overestimation of GHG emissions due to forest fires in longer perspective because the most of the forest fires are located in small region around large cities and repeated forest fires will not cause equal level of emissions in comparison to the first forest fire.

Impact on GHG emissions depends from life-time of the measure, probability of the forest fire and probability of repeated forest fires in the same place. Quantitative impact on GHG emissions is not evaluated yet in Latvia; however, the importance of this measure is recognized.

The measure conforms with the forest management sustainability criteria. Cost benefit ratio is not estimated yet in Latvia.

Prevention of forest fires avoid emissions of harmful substances like PAHs, dioxins, thus contributing to maintenance of healthy environment, as a measure aimed at reduction of risk f natural disturbances fire prevention contributes to increase of deliveries of roundwood logs and solid biofuel.

Maintenance of fire prevention systems is supported in Latvia 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).

3.6.4 Implementation of depth-to-water maps to improve forest management and production planning

Organic soils non-specific measure, which can be implemented on all kind of soils. The most significant impact can be reached in forests with wet and drained soils temporarily or locally suffering from exceeding water. The measure is identified as potentially valuable in Latvia. Is is also closely related to other water regime related measures and significantly improves efficiency of these measures, therefore it is proposed as separate measure having significant impact on different aspects of forest management.

The potential impact of this measure as implementation of new forest management planning principles, including planning of forest operations, is not yet evaluated. The scientific evaluation of the measure, except for transport and energy sector, should be done as for a complex solution considering different opportunities for utilization of water regime maps (Ivanovs, Sietiņa, et al., 2017; Ivanovs, Sietina, et al., 2017).

Stand wise forest inventory and NFI data are insufficient to evaluate impact of application of he water regime maps in forest management planning. These data sources should be supplemented with supplemented with continuously updating information on water regime and soil bearing capacity. Potential growth impact can be then estimated using growth models. Savings transport and energy sector can be determined using StanForD 2010 standard data from harvesters and forwarders; however affected area needs to be developed.

The measure have continuous impact; however, savings of fuel in transport and energy sector appears in the year for harvesting. Additional measures are implementation of the forestry good practice guidelines during the rotation and efficient utilization of the produced biomass. Quantitative impact of the measure in Latvia is not yet estimated. Cost – benefit ratio is not estimated yet too; however, methodologies for implementation of water regime maps are under development.

No biodiversity related issues are known. Reduction of impact of forest operations on the environment is in line with the sustainability criteria of forest management. The measure is directly aimed reduction of GHG emissions in energy and transport sector. Better information of soil bearing capacity will also improve planning and outputs of harvesting residues and low grade biomass suitable for energy wood production.

The measure is not supported in national policies in Latvia. The development of necessary technologies are proposed in Joint stock company "Latvia's state forests" long term research programs.

3.6.5 Prevention of wind throws and snow-break risk by intensified rotations and more resilient stand composition

Organic soils non-specific measure, which can be implemented on all kind of soils; however, in light of climate change (non-frozen soil in winter and more often strong wind occurrences) this measure have particular importance in forests with organic and shallow (thin aerated soil layer). The measure is identified as potentially valuable in Latvia.

Methods for quantitative assessment of impact of this measure are not developed yet. Such methods has to be elaborated within the scope of development of risk management system in forestry, which includes timing and intensity of thinning, selection of soil scarification methods, fertilization and other measures). National scale projections has to be used and extrapolated to local level where possible, due to complexity of interaction of different parameters.

There are maps and models providing basic information on windthrow risk, which can be used at national level for evaluation of risk of wind throws and snow breaks by using probabilities of natural disturbances depending from stand location, stand age and other parameters, however, knowledge on interactions of different parameters, particularly at a spatial level is insufficient and they are not implemented in an integrated modelling solution (Seidl et al., 2014).

The impact of the measure is continuous at a national, in spite at local level it can have occasional character due to high uncertainty of natural disturbances. Quantitative impact is not estimated yet in Latvia.

There are no non-compliances with the sustainability criteria. Implementation of the measure ensures formation of more resilient and sustainable forest stands. Additional costs are development of planning tools and training of forest owners. Planning measures preventing damages due to wind throws and snow breaks contributes to larger and more predictable future deliveries of roundwood logs and solid biofuel to industry.

Windthrow risk management is included in forest regulation as requirement to consider neighbouring forest stands during releasing of harvesting permission.

3.6.6 Reduction of risk of distribution of pests by increase of resilience of forest stands

Organic soils non-specific measure, which can be implemented on all kind of soils. The measure is identified as potentially valuable in Latvia.

National scale methods for quantitative assessment are not developed yet. Similarly to windthrow and snow break impact assessment tools, such methods has to be elaborated within the scope of development of risk management system in forestry. National scale projections has to be used and extrapolated to local level where possible. However, simplified approach can be used for measures like plant protection or extraction of stumps, which have predictable, but still poorly investigated, impact on growth rate. For such measures adopted growth models and assortment tables can be used to evaluate the impact.

There are maps providing basic information on the risks according to current information, however they have to be updated to consider probabilities of forest management and dynamic structure of forests so that they can be used at national level for evaluation of risk of distribution of pests and diseases. Stand wise forest inventory, as well as the NFI needs to be updated to represent data on implementation of the measures like forest protection. Knowledge on interactions of different parameters affecting distribution of pest and diseases are insufficient and they are not yet implemented in an integrated modelling solution. Implementation as well as impact assessment should be done at national scale.

The impact of the measure is continuous at a national, in spite at local level it can have occasional character due to high uncertainty of natural disturbances. Quantitative impact is not estimated yet in Latvia, especially, considering significant impact of already applied practices, which are incorporated into forest management practices.

There are no non-compliances with the sustainability criteria. Implementation of the measure ensures formation of more resilient and sustainable forest stands. Prevention of distribution of pests and diseases contributes to increase of the future deliveries of roundwood logs and solid biofuel to industry. The measure also makes deliveries and cost of roundwood and biofuel more predictable.

Monitoring of pests and diseases is funded by government and early alarm system is established to prevent escalation of natural disturbances. Forest owners are not financially supported to implement plant protection measures. No national scale strategy is developed.

3.6.7 Slowing down of root rot distribution

Organic soils non-specific measure, which can be implemented on all kind of soils; however the most significant impact can be reached in forests with wet and drained soils suffering from nutrient shortage and other threats. The measure is identified as potentially valuable in Latvia.

Assortment planning models can be used to evaluate carbon input into HWP pool; however, projections of impact of different measures and their combinations needs to be developed. The impact on growth curves and carbon input into other pools except HWP needs to be developed. Impact of temporal changes of dominant species can be evaluated using growth models; however, impact of changes in growth conditions, for instance, due to accumulation of nitrogen by alder, cannot be estimated using available data.

Stand wise forest inventory as well as NFI do not contains information on root rot distribution and risk of spreading of this disease depending from growth conditions and characteristics of surrounding stands. The impact on HWP pool starts with the next felling – thinning or regenerative felling. The measure have continuous impact through several generations of trees. Additional measures are timely thinning and regenerative felling, as well as optimal structure of assortments, respectively, share of energy wood and pulpwood should not be increased. Quantitative impact of the measure in Latvia is not estimated yet, scientific substantiation of the measure needs to be improved (Arhipova et al., 2011; Brūna et al., 2015; Gaitnieks et al., 2018; Kļaviņa et al., 2016).

No biodiversity loss related issues of this measure are known; however, stump extraction, spreading of chemicals or fungal suspensions or temporary change of dominant species may be considered as measures having potentially significant impact on biodiversity. At the same time these measures increase resilience of the affected forest stands ensuring that they are able to provide ecosystem services in long term.

Information of the potential GHG emission reduction at a national scale is not known, therefore the cost-benefit ratio can't be estimated. Use of fungal specimens and urea takes place in the industrial therefore this measure is already considered as economically efficient.

The measure is targeted to increase of resilience of forest ecosystems, respectively it will increase future deliveries of HWP contributing to substitution in wood processing related industries. The measure may have insignificant adverse impact on output of energy wood due to reduction of proportion of low grade biomass.

The measure is not supported in national policies; however, it is implemented (stump treatment) at industrial scale in state forests in regenerative fellings.

CONCLUSIONS

1. The potential role of the organic soils 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 land use change to grassland or forest land, highlights significant regional differences and knowledge gaps on preconditions for the GHG emission reduction.
2. National policies and climate change mitigation strategies recognizes the potential role of organic soils in the reduction of GHG emissions in LULUCF and agriculture sector; however, only few measures considered in national policies, e.g. regulation of water regime and restoration of peat extraction sites in Finland and Estonia, are directly addressed to organic soils. The most of the measures, e.g. afforestation and conversion of cropland to grassland, may have indirect impact assuming that certain proportion of the affected areas will be with organic soils.
3. National climate change mitigation policies usually lacks quantitative assessment of the measures proposed in LULUCF sector, particularly, no quantitative targets in terms of the reduction of GHG emissions are set for organic soils in the National reports on progress of implementation of LULUCF action plans according to EU decision 529/2013 Article 10 and National reports on policies, measures and emission projections according to EU monitoring decision 525/2013 Article 13 and 14.
4. Expert questionnaire based evaluation of the climate change mitigation measures applicable in areas with organic soils identified 41 measure; mostly measures, which can be applied in areas with organic and mineral soils, 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 and knowledge about the impact on GHG emissions from soil is limited.
5. National LPIS systems, including production related data bases, as well as soil maps and moisture regime modelling tools should be improved to ensure ability to estimate and to project the impact of the proposed climate change mitigation measures. Country specific methodologies verifying the impact of the proposed climate change mitigation measures should be developed and integrated with the models applied in the GHG inventories and National reports on policies, measures and emission projections.

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Annex 1: Summary of expert judgement based evaluation of climate change mitigation measures

Table 19: Expert judgment based evaluation of climate change mitigation measures

Title	Substantiation of the impact	Criteria for site selection	Addressed carbon pools and GHG emissions	Knowledge gaps to be filled, uncertainties, collaboration needed
Use of improved planting material in forest regeneration utilizing existing achievements of forest breeding	The measure ensures additional CO_2 removals due to use of forest breeding effect and larger output of commercially valuable assortments used for production of HWP with long term carbon storage potential. Use of genetically more valuable material ensures 15-20% higher growth rate in the next rotation of trees. Adaptation effect can also contribute to climate change mitigation; however, this effect can't be easily estimated. Carbon stock in dead wood, litter and soil pools is increasing due to bigger biomass production and litter input. Shorter rotation may increase carbon inputs significantly. The implementation of the measure also affects surrounding stands regenerated naturally due to availability of high value seed material in surrounding stands. This impact can't be evaluated with currently available knowledge.	All forest lands where management is permitted and other environmental conditions (high groundwater level, shortage of nutrients) are not limiting growth of trees. In case of drainage additional reduction of CH_4 and N_2O emissions can be considered.	All carbon pools including mineral and organic pools.	Integrative impact of different measures, like breeding and shortening of rotations. Impact on other carbon pools, particularly on dead wood, litter and soil.
Continuous-cover forestry	Continuous-cover management with reduced ditch network maintenance aims at maintaining a moderate WT at all times, sustaining C sequestration and litter inputs by the tree stand at all times, and sustaining more even flow of income and reduced management costs to the forest owner than rotation-based management. Continuous-cover management may be done by selective cuttings maintaining an uneven-structured stand, or by strip harvesting, regeneration with advanced understorey were feasible, harvesting small gaps, or a combination of these. The basic idea is to maintain sufficient tree stand canopy mass for sufficient biological drainage, and maintain only some critical ditches, instead of maintaining an extensive, deep	Selective cuttings for spruce-dominated stands with existing uneven-structural features; regeneration utilizing existing understorey in all sites where sufficient understorey is present, small gaps in spruce-dominated, even-structured stands, strip harvesting in any stand type.	Soil C pool, tree stand C pool, soil CO_2 and N_2O emissions	No peer-reviewed publications on the impacts on soil emissions, soil C stock, tree stand productivity, yield, or economic outcome yet. Collaboration with other projects will be done, as well as soil emission measurements in this project's reference sites.

Title	Substantiation of the impact	Criteria for site selection	Addressed carbon pools and GHG emissions	Knowledge gaps to be filled, uncertainties, collaboration needed
	ditch network, as well as maintain feasible conditions for natural regeneration. WT below 30 cm from soil surface during summer time has been estimated to be sufficient for maintaining tree growth and preventing significant CH_4 emissions. At other times of the year, the WT may, and will, be somewhat higher. Motivation for expected impact: Conventional management means stand rotation of usually several decades, final felling, and regeneration by planting in nutrient-rich organic soils. Following final felling, the water-table level (WT) usually rises close to the soil surface. This may cause CH_4 emissions and high output of water-borne C (especially DOC) and N. Following the soil disturbance by the operation, decomposition rate of the peat soil may increase, but decomposition takes place in a more limited oxic layer (due to rising WT), and thus, the overall heterotrophic CO_2 emission may not increase. Anyway, the net ecosystem exchange is still clearly negative at least for some years, due to the lack of carbon-sequestering vegetation. In mature, high-volume stands on the other hand, WT may be quite deep as the biological drainage by the tree stand, achieved by efficient evapotranspiration, adds of the drainage achieved with a ditch network in efficiently drained sites. Deep WT increases soil CO_2 emissions much more than it reduces CH_4 emissions. Also, there may be rather high N_2O emissions from efficiently drained nutrient-rich organic soils, and those are especially high following final felling.			
Pre-commercial thinning to improve species composition, increase growth rate and reduce	Pre-commercial thinning contributes to additional increment during certain period of time. Support to forest thinning will result in rapid and significant increase of carbon stock in living biomass with long	All forest forests on organic soils where management is permitted and other environmental conditions (high groundwater	All carbon pools.	Improvement of current LPIS to provide better modelling input for evaluation of short term and long term impact,

Title	Substantiation of the impact	Criteria for site selection	Addressed carbon pools and GHG emissions	Knowledge gaps to be filled, uncertainties, collaboration needed
rotation length	lasting impact on carbon stock in dead wood, litter, soil and HWP. Additional impact of the measure is ensured by replacement of dominant species by commercially more valuable species. It is still complicate to prove and quantitatively assess impact on the dead wood, litter, soil and HWP pools, therefore these pools are not included in the estimation of the impact.	level, shortage of nutrients) are not limiting growth of trees.		including current forest status in growth potential (nutritional regime and wearing of drainage systems); improvement of models.
Fertilization with wood ash instead of ditch network maintenance	Regular maintenance of an efficient ditch network sustains deep drainage that increases soil emissions of CO_2 and N_2O in nutrient-rich organic soils. The actual impact of deep drainage is through better nutrient availability for the tree stand. Similar impact may be achiever with fertilization with wood ash, which is a "perfect" fertilizer for nutrient-rich organic soils, since it does not contain any N, which is usually in high supply in such sites naturally, but has a high content of, e.g., phosphorus and potassium, which may be in very short supply in such sites. Ash may clearly increase tree stand production and litter inputs to the soil. It has not been observed to increase soil GHG emissions in short term. It may increase peat soil decomposition in long term, but such results are from sites with effective drainage and may not hold for sites with reduced drainage.	Most nutrient-rich organic soils	All ecosystem carbon pools	Interaction between different management measures to improve forest growth and CO_2 removals, e.g. thinning intensity, fertilization, rotation length. Application of this method in naturally wet forests.
Application of mineral fertilizers (N, P, K) and reduction of rotation length	Complex forest management measure combining forest fertilization, pre-commercial thinning, commercial thinning and regenerative felling. Fertilization involves application of mineral fertilizers to increase removals in living biomass. P and K with or without N can be applied 10-15 years before commercial thinning or regenerative felling. It can be done once per rotation (before regenerative felling) or several times (2-4) per	All forest lands on organic soils where management is permitted and other environmental conditions (high groundwater level) are not limiting growth of trees. In fertile stand types impact of nitrogen might not be visible, therefore these stand types might response to additions of complex	All carbon pools	Optimization of fertilizer dosages and management systems in different conditions, integration of different management measures to ensure synergy with forest fertilization, impact on other carbon pools, particularly, soil,

Title	Substantiation of the impact	Criteria for site selection	Addressed carbon pools and GHG emissions	Knowledge gaps to be filled, uncertainties, collaboration needed
	rotation applying fertilizer right after thinning. In combination with more intensive and regular thinning fertilization can double CO_2 removals in forest lands. Fertilization has short term and long term impact, which is complicated to evaluate.	fertilizers – nitrogen and phosphorus or potassium. For some species impact of fertilizers is not evaluated yet or low value of wood makes fertilization economically inefficient.		ground vegetation and litter. Measures to verify impact of fertilization, as well as to select stands suitable for fertilization and estimation of dosage using remote sensing data. Forest growth models should be supplemented with ability to calculate impact of fertilization.
Recycling of wood ash in forest (pure ash or mixture with N fertilizer on poor soils)	Complex forest management measure combining wood ash recycling and application of wood ash and N containing fertilizers. Similarly to forest fertilization with mineral fertilizers this measure integrates application of wood ash, pre-commercial thinning, commercial thinning and regenerative felling and, particularly, maintenance of drainage systems. Wood ash or mixture of fertilizers can be applied 10-15 years before commercial thinning or regenerative felling. Respectively it can be done once per rotation (before regenerative felling) or several times (2-4) per rotation applying wood ash right after thinning. Strip roads are mandatory necessary for all types of fertilization, therefore permanent network of strip-roads is necessary. In combination with more intensive and regular thinning fertilization can double CO_2 removals in forest lands. Wood ash has easily accessible short term and uncertain long term impact.	All forest lands on drained organic soils where forest management is permitted. Improvement of accessibility might be necessary for some areas. Spreading of wood ash should be done on frozen soils or when soil is dry and bearing capacity is optimal.	All carbon pools, N_2O and CH_4 emissions	Impact on non-CO_2 emissions, including effect of groundwater level. Optimization of wood ash dosages and management systems in different conditions, integration of different management measures to ensure synergy with wood ash recycling, impact on other carbon pools, particularly, soil, ground vegetation and litter. Measures to verify impact of fertilization, as well as to select stands suitable for wood ash recycling and estimation of dosage using remote sensing data. Forest growth models should be supplemented with ability to calculate impact of wood ash recycling.

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Drainage and intensification of forest management on fertile wet organic soils	Complex forest management measure integrating drainage, forest thinning, regenerative felling, wood ash recycling and fertilization where necessary. The primary effect is considerable increase of removals in living biomass of trees and ground vegetation. The effect takes place right after drainage and continues until regenerative felling or longer, if drainage system is restored before and after regenerative felling. The impact of drainage on soil emissions depends from the accounting method – if soil emissions from naturally wet soils are accounted and the impact of drainage is difference between emissions from wet and drained soils or wet soils are considered emission neutral. The effect of drainage can be increased by application of wood ash, mineral fertilizers or mixture of these materials. Limited information about GHG emissions is available on both - wet and drained soils. The measure interferes with other measures like pre-commercial thinning and regeneration with improved planting material.	Forest lands on naturally wet organic soil, where forest management is not permitted. Nutrient poor sites are not suitable for drainage.	All carbon pools and non-CO_2 emissions. Reduction of CO_2 emissions from soil can be negative. Detailed groundwater level information might be necessary to estimate the level of emissions.	Impact of drainage on soil GHG emissions, both on mineral and organic soils. Implementation of the measure into the forest growth model, impact of drainage on ground vegetation. GHG emissions from naturally wet soils.
Improvement of genetic properties and adaptiveness of planting material (continuous investments in forest breeding)	Forest breeding contributes to continuous increase of forest productivity by improvement of genetic properties of planting material and seeds, which leads to higher yields in forests. The measure is closely related to the forest regeneration measure providing continuous improvement of planting material.	This measure considers investments in research, seed orchards and clonal testing.	All carbon pools	Projections of long term impact of climate change mitigation effect of breeding program; particularly, on synergies with risk management.
Maintenance of existing drainage systems after regenerative felling	Normally, if culverts are maintained, depreciation of ditches do not cause significant deterioration of growth conditions in forest stands due to ability of forest stand to regulate water regime. Exceptional cases are intense thinnings or selective fellings, extreme climate conditions or defoliation due to diseases or pest expansions, which can destroy self-	The impact of the measure should be associated with regenerative felling or selective felling considerably reducing basal area of forest stand. Very poor soils (former raised bog) with limited growth potential should not be	Living and dead biomass carbon pool, including harvested wood products.	Impact on soil carbon pool and non-CO_2 GHG emissions cannot be evaluated due to lack of reliable research data on rewetted soils. Decomposition of dead wood in rewetted areas may be

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	regulatory ability of forest stands resulting in considerable damages or disease of forest stand. After regenerative felling depreciated ditches cause increase of groundwater level and can negatively affect forest regeneration and growth potential resulting in decrease of growth rate, which follows to the curves typical for naturally wet soils instead of growth curves typical for drained soils, which means considerable smaller removals in living biomass and all other carbon pools. Maintenance of drainage ditches ensures that the next rotation of trees will follow to the growth curves of forests on drained soils. Additional measures like use of improved planting material, ash spreading, fertilization, shortening of rotation length can increase removals even more – up to 2 times in compare to previous rotation.	considered where it is possible, however, use of wood ash can improve growth conditions considerably in such areas too providing opportunity to utilize wood ash in safe way.		slowed down, which can significantly affect net emissions from soil. Different management options needs to be evaluated according to impact on net GHG balance.
Remedial ditching to enhance regeneration of forests on wet soils after regenerative felling	Remedial ditching can shorten forest regeneration period and increase removals in forests on naturally wet mineral soils, however, it can affect regeneration results and growth rate also on organic soils by improvement of water regime during the first decades after regenerative felling. The impact of this measure is due to shorter rotation period, due to better species composition in regenerated stands and due to improved growth rate at middle and maturity age. Remedial ditching is also important to ensure the additional effect of the tree breeding and pre-commercial thinning.	Forests on fertile naturally wet organic soils. This method is applicable also on dry mineral soils, areas where optimal water regime is dominating, but improvement of growth conditions is necessary in some parts of compartments.	All carbon pools, CH_4 emissions from soil	Very limited information is available about remedial ditching and it's impact on GHG emissions. Basically it is similar to forest drainage and maintenance of existing drainage systems. Detailed information is necessary about GHG emissions from naturally wet organic soils if remedial ditching is done or not. Different age groups, soil fertility classes and dominant species should be evaluated. Impact of remedial ditching on biodiversity has to be evaluated to create synergies between different

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				forest management targets.
Intensification of management and reduction of rotation (partially overlaps with pre-commercial thinning, but extends it with more significant changes in forest management)	Reduction of rotation cycle is associated with more intensive thinnings resulting in larger dimensions and output of roundwood assortments suitable for HWP with long service period; shortening of rotation contributes also to accumulation of dead wood storage (stump biomass); however, it reduces mortality and input into dead wood pool. This measure primarily can be implemented on fertile soils, where potential negative impact of other factors like exceeding surface water or shortage of nutrients is relatively small making the expected impact less uncertain. The measure is closely associated with other forest management activities, like use of high quality planting material, timely thinning, forest protection measures and regenerative felling. Fertilization can significantly increase CO_2 removals in living biomass and contribute to shortening of rotation period.	Young forest stands on fertile soils without management restrictions. Replacement of species should be considered in sites with low valued species composition in regenerative felling. Management intensity can be increased in young stands. This measure is no suitable for mature stands, except areas where regenerative felling is planned and intensification of management can be started with proper selection of species and regeneration method.	All carbon pools	Knowledge base on response of forest growth to intensification of forest management is limited, particularly on intensification of thinnings, decomposition response of dead wood carbon pool etc. Experimental data needs to be obtained in different conditions and climate regions wide research data needs to be synthesized in the models to reduce uncertainty caused by insufficient historical data at a national scale.
Reconstruction (regeneration) of low valued forest stands	Additional removals in living biomass due to additional increment. Removals in other carbon pools including HWP are also increasing. Increase of the removals is associated with changes in species composition and management, leading to better considerations for the future increments. The impact of the measure depends from further management activities.	Forests on fertile soils with non-valuable species composition or small growing stock.	All carbon pools	The criteria for selection of suitable stands and application of additional measures to be implemented during the forest regeneration needs to be developed, particularly, remote sensing tools applicable at a single stand level.
Regeneration of forests after natural disturbances	The measure is similar to reconstruction of low valued forest stands; the aim is to shorten forest regeneration period and to improve composition of the following generation of trees by artificial regeneration of forest stands after natural	Forests which needs to be regenerated after natural disturbances, except nature conservation areas, where further management activities are	All carbon pools	Adopted planning tools for risk management in future forest generations

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	disturbances. Additional removals in living biomass due to additional increment are considered. Removals in other carbon pools including HWP are also increasing in comparison to baseline scenario – natural regeneration. The impact of the measure depends from further management activities therefore this is long lasting and complex measure, which will give the most of the additional value in combination with use of improved planting material, pre-commercial thinning, fertilization and other intensification measures.	restricted.		
Rewetting of low valued drained forests with limited growth potential	Rewetting of nutrient-poor organic soils with very low growth potential can be rewetted assuming accumulation of CO_2 in peat layer. Impact of the measure is not well demonstrated, controversial results are available from different sources. The impact of the measure is substantiated by accumulation of CO_2 in soil and by reduction of N_2O emissions; however the reduction of CO_2 emissions can be partially or fully compensated by increase of CH_4 emissions. Reduction of N_2O emissions after rewetting is doubtful due to numerous evidences of very high N_2O emissions from naturally wet and rewetted areas. Further studies are necessary to evaluate GHG balance in long term comparing drained and rewetted areas, as well as pre-conditions for reduction of GHG emissions. Alternate option for rewetting is improvement of growth conditions by application of wood ash and nitrogen fertilizer. This would be especially preferable in areas surrounding heat and power plants producing wood ash. Processed wastewater sludge can be used as source of nitrogen. Rewetting will also contribute to reduction of risks associated with spreading of diseases due to weakening of stands on nutrient-	Drained forests on nutrient poor organic soils representing the lowest site indexes, where rewetting can be done without interfering with growth conditions in surrounding areas.	Soil carbon pool, carbon stock changes in dead and living biomass needs to be considered	Impact of rewetting on soil carbon stock changes, GHG emissions and Hg outputs from soil.

Title	Substantiation of the impact	Criteria for site selection	Addressed carbon pools and GHG emissions	Knowledge gaps to be filled, uncertainties, collaboration needed
	poor soils.			
Introduction of innovative soil scarification methods and improved planting material to reduce regeneration period	Introduction of mounding lead to reduction of forest regeneration period ensuring more rapid accumulation of CO_2, especially in fertile stand types, which in its turn leads to shortening of rotation period and intensification of CO_2 removals in all carbon pools including HWP. Mounding is especially efficient on fertile naturally wet soils where mounds gives advantages to the planted trees during the first decades after the forest regeneration. There are also evidences of reduction of wind damages in areas scarified using mounding method, which is also contributing to increase of CO_2 removals in living biomass and other carbon pools. Mounding can also have impact on soil GHG emissions, particularly reduction of CO_2 and N_2O emissions from soil in comparison to disc trenching; however, smaller scarified area can also lead to increase of CH_4 emissions in comparison to other scarification methods.	Forests on nutrient-rich soils including forests on naturally wet and drained soils without management restrictions.	All carbon pool	Impact on soil GHG emissions and long term impact on productivity and resilience of forest stands regenerated using mounding or alternate methods. Forest management intensification approaches needs to be evaluated.
Afforestation of farmlands on organic soils	There are 4 alternatives of afforestation – intensified short rotation forests (plantation forests in some countries) aimed at maximizing of production (e.g. spruce stands with 40 years rotation), extensified forest management systems following to management rules applicable in conventional forests (e.g. spruce stands with 80 years rotation period), perennial woody crops considering 2 potential scenarios – plantations with 20-30 years rotation (e.g. hybrid poplar or hybrid aspen for pulp and bioenergy) and fast growing crops for biofuel production (e.g. willow plantations). The latest 2 options are described further. Under this measure only classical approach of afforestation is evaluated.	Grassland and cropland on organic soil where afforestation is permitted according to national and local regulations	All carbon pools	GHG emissions in nutrient rich organic soils and transition period to reach steady stage after afforestation, as well as impact of wood ash application on GHG emissions.

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	Afforestation leads to increase of carbon stock in living and dead biomass carbon pool including litter by recreation these pools and increase carbon stock in soil. Notably that CO_2 removals in soil due to afforestation may be underestimated because changes of the soil bulk density is not considered. Afforestation also affects non-CO_2 emissions from soil, however this impact may be either negative or positive. Intensified management should be associated with fertilization to boost increment.			
Conversion of wet grasslands into woody paludicultures for HWP and biofuel production (grey alder and other water tolerant species in afforested farmlands)	Some of the grasslands can be rewetted or are already rewetted due to depreciation of drainage systems or maintenance of drainage systems is associated with considerable expenses or organizational issues like agreements between multiple land owners. In such cases afforestation of wet soils with water tolerant species (alders, birch) can be considered as viable option for reduction of GHG emissions. Net reduction of GHG emissions will be ensured by CO_2 removals in living biomass, which will contribute also to CO_2 removals in dead wood and litter. Afforestation in such areas most probably will require mounding or remedial ditching to improve growth conditions at least in a part of the stand during regeneration period. Impact on soil GHG emissions is not substantiated sufficiently; however, there might be cases when GHG emissions from soils increase after establishment of forest stands, especially if it is associated with periodic increase of groundwater level. Management of forest stands on wet soils is associated with high risk of natural disturbances resulting with disease of a stand; therefore commercial value of such stands should be considered carefully. It is also important to point out that implementation of this measure	Low value grasslands with already rewetted organic soils (depreciated drainage systems) or areas that can be rewetted, where reclaiming of drainage system is too costly or technically or administratively complicated, as well as nature conservation areas, where afforestation is permitted.	All carbon pools, impact on soil GHG emissions depends from initial conditions and water regime after establishment of paludiculture	LPIS systems needs to be supplemented with data on soil type, nutrition regime, groundwater regime and future projections of drainage system status. Emission from soil from rewetted grassland and woody paludicultures of different age needs to be determined, as well as transitional period when the GHG emissions reach steady stage.

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	doesn't mean leaving of an area on it's own, but active and costly management actions, like soil scarification, planting, tending and regenerative felling should be considered.			
Intensive cultivated SRF in nutrient rich organic soils (territorially overlaps with afforestation using conventional methods)	Two alternatives are considered in this study – intensified management of short rotation forests (SRF) with 15-25 years rotation (e.g. hybrid aspen, poplar or alder) for solid biofuel, pulpwood and roundwood production and short rotation coppice (SRC) with 3-7 years rotation (e.g. willows) for solid biomass production. SRF are considered as alternative for plantation forests or conventional forest management systems in afforested areas. SRC is considered as an alternative for utilization of wastewater sludge and wood ash, respectively, the expansion of SRC depends from availability of wastewater sludge. Climate change mitigation impact is substantiated by removals of CO_2 in living and dead woody biomass, litter, soil and HWP, as well as replacement effect in energy sector as far as it can be considered.	Grassland and cropland on nutrient-rich soil where afforestation is permitted according to natural and local regulations are suitable for SRF; fields with well drained soil, flat terrain and regular form are useful for SRC.	All carbon pools including litter, to limited extend; HWP pool only in SRF. SRC contributes mainly to substitution of fossil fuels in energy sector and to reduction of GHG emissions in waste sector due to utilization of wastewater sludge	Impact on soil carbon stock of SRC and SRF is not sufficiently substantiated. Development of new clones and standardized SRF and SRC solutions for different growing conditions needs to be continued covering different climatic regions to ensure resilience and adaptivity of the developed systems.
Elimination of hotspots of methane emissions – establishment of shallow ditch network to ensure aeration of topsoil layer.	Methane emissions from soils correlates with soil aeration regime and dynamics of groundwater level during the season; poor aeration and fluctuating groundwater level are contributing to increase of GHG emissions from soil. Compartment level improvement of growth conditions can be done by continuous drainage or remedial ditching. However, there is still variation of aeration regime within a stand resulting in the increase of CH_4 emissions from depression areas within a stand. These emissions can be avoided by removal of exceeding water using network of shallow (30-40 cm) ditches which can connect depressions with drier areas or existing	Selection of suitable areas has to be done using high resolution terrain data and water regime maps to detect areas accumulating surface waters. Further terrain data analysis has to be done to identify if a network of shallow ditches can help in improvement of water regime / soil aeration.	All carbon pools, N_2O and CH_4 emissions from soil	Wet area maps needs to be developed and implemented into LPIS system. Tools for planning and impact assessment of network of shallow ditches is necessary to evaluate impact of the measure. Emission factors (CO_2, N_2O and CH_4) has to be developed to characterize impact of the ditching on GHG emissions. Long term evaluation is necessary

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	ditch network. Improvement of soil aeration increase accessibility of nutrients and improve growth of trees in depressions. Drainage can also increase CO_2 emissions due to decomposition of soil organic material; however, this effect is at least partially compensated by additional removals in living biomass supplementing all carbon pools. Improvement of growth conditions will also reduce risk of natural disturbances indirectly contributing to higher removals in long term.			considering that removals in living biomass can substitute CO_2 emissions from soil after forest stand reach certain age.
Fire prevention – mineralized belts, early warning systems, better equipped fire safety departments	Forest fires is considerable potential source of GHG emission, which is significantly suppressed by continuous implementation of fire prevention targeted measures, like establishment of mineralized belts to stop ground fire, building of watch towers and installation of automated fire and smoke detection systems which ensures rapid detection of spreading of forest fires. Development and maintenance of forest road network can also be considered as a measure making forests accessible for fire-engines. Implementation of the measure (maintenance and improvement of fire prevention systems) contributes to reduction of GHG emissions and maintain growth potential in forests. This measure is particularly important for organic soils where ground fire can become a huge source of GHG emissions and other pollutants.	All forests on organic soils, especially young coniferous stands on drained soils	All carbon pools and GHG emissions due to forest fires	Models providing ability to calculate avoided GHG emissions due to fire prevention measures.
Prevention of wind throws and snow-break risk by intensified rotations and more resilient stand composition	Implementation of forest management measures reducing risk of wind throws and snow breaks like reduction of forest rotations (this measure refers to intensification of forest management); more advanced planning of regenerative fellings and thinnings (considering dominant wind direction, structure of bordering stands and drainage	All forests, particularly areas subjected to higher windtrow or snow break risk in future.	All carbon pools	Modelling framework and planning tools integrating spatial, climate, growth and management parameters for evaluation of probable wind damages under different management scenarios.

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	conditions), more intensive early thinning to increase resilience of forest stands. Stand composition during the regeneration should consider future risks to avoid formation of highly vulnerable forest blocks. The measure is aimed to ensure continuously high growth potential of forests, to avoid spreading of secondary disturbances like pests and diseases invading weakened trees and dead trunks. Basically the measure results in higher carbon stock in all carbon pools. The necessary actions are partly addressed in other measures and additional value here is different, long term forest management planning approach considering research findings and proposed distribution of risks, e.g. regions subjected in future to the most severe wind throws.			
Reduction of risk of distribution of pests by increase of resilience of forest stands	The measure is targeted to support forest management approaches, which reduces risk of spreading pests and diseases, particularly, on future threads. Some of these approaches are already mentioned as separate measures, like maintenance of drainage systems, spreading of wood ash in organic soils, fertilization of forests on nutrient-poor soils, timely thinning, forest regeneration after salvage logging and use of improved, more resilient planting material. These measures can be applied in more integrated way considering local conditions based risk analysis, spatial information on dynamic forest structure in the region, additional measures that can be implemented like adopted species composition or plant protection after regeneration using chemical or mechanical agents.	All forests with particular attention to areas highlighted by the risk analysis	All carbon pools	Modelling framework integrating spatial, climate, growth and management parameters for evaluation of probable wind damages under different management scenarios. National strategy for adaptation to climate change and ensuring of resilience of forests.
Adaptation of drainage systems to optimal depth of groundwater and inflow to	Fluctuations of groundwater level in drained forests is important factor affecting GHG emissions from soil. This measure is extended alternative for	Forests without management restrictions	GHG emissions from soil	Impact of the measure on GHG emissions needs to be evaluated and optimized to

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avoid CH_4 emissions and to reduce CO_2 emissions	maintenance of drainage systems considering adaptation of drainage systems to maintain optimal level of groundwater to avoid CH_4 emissions and to keep CO_2 emissions low. Depending from site fertility class the depth of groundwater level can be increased or lowered to ensure that certain amount of nutrients is available for trees (in nutrient-poor soils deeper drainage systems can improve growth without increasing CO_2 emissions) ensuring at the same time reduced amount of CH_4 emissions. Scientific evidences of efficiency of this measure are insufficient, as well as technical solutions which can be implemented to ensure the proposed impact on groundwater level. Steady groundwater level will also contribute to reduction of natural disturbances thus contributing to increase of carbon stock in living biomass and other carbon pools.			maximize the impact of the measure. Synergies with other measures, like maintenance and building of new drainage systems, stand level shallow ditch network and others. National strategies are necessary to implement the measure at a national scale.
Avoiding degradation of natural surface water flows during thinning and regenerative felling	Commercial thinning, regenerative felling and soil scarification can have negative impact on water regime in a forest stand due to soil compaction and creation of artificial barriers to natural water streams having adverse effect on forest growth. This effect can be avoided by implementation of proper planning methods considering terrain and soil properties, therefore the impact of the measure can be expressed as higher growing stock and reduced GHG emissions from soil. The measure also reduces risk of natural disturbances, which transfers into higher growth rate and more predictable prices and deliveries.	The measure is applicable on all forests where degradation of surface water flows can have adverse impact on growth conditions due to increase of groundwater level and worsening of soil aeration.	All carbon pools, soil GHG emissions	Methods for characterization of water regime are under development now; however, data available for characterization of changes in water regime and potential impact on GHG emissions is insufficient.
Slowing down of root rot distribution (stump treatment, stump extraction)	Root rot is one of the main drivers for deterioration of timber quality and output of HWP in coniferous stands. The measures aimed at reduction of distribution or even elimination of this disease	Primarily coniferous forest stands subjected to high risk of root rot distribution or already heavily infected by root rot. Stump	All carbon pools, primarily HWP	Activity data, biomass models and modelling parameters needs to be developed to characterize impact of root

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	disease are very important to reach climate change mitigation targets. This measure address forest management activities not mentioned above - stump treatment with fungal preparats and urea during commercial thinning and regenerative felling, stump extraction after regenerative felling to reduce amount of infected biomass and introduction of intermediate rotation of trees like grey alder between 2 rotations of coniferous trees or combination of these measures. Implementation of the measure will increase output of HWP and will also contribute to increase of living biomass, dead wood and soil carbon pool. Carbon losses due to stump extraction will be partially compensated by substitution effect in energy sector.	extraction and temporary replacement of dominant species can only be implemented in areas where regenerative felling is not prohibited.		rot and alternative scenarios, considering growth conditions, implementation of mitigative measures, on growth of trees and output of HWP.
Implementation of depth-to-water maps to improve forest management and production planning	Forest management planning related measures aimed at better integration of different management related measures, e.g. forest regeneration, maintenance of drainage systems, remedial drainage, network of shallow drainage ditches in stand and others. This measure is precondition for efficient implementation of above mentioned measures. Considering that mapping of water regime planning can be clearly distinguished from other activities in forest, it is listed also as separate measure. wetness indexes derived from such maps can also be used for early identification of problems in forests, e.g. depreciation of drainage systems. Maps of water regime can also be used in decision making on forest regeneration (selection regeneration and soil scarification method, selection of species and thinning procedure) and harvesting methods (use of harvesting residues in strip-roads or production of solid biofuel). In parallel to broad applicability in forestry to improve forest growth	All forests without management restrictions.	All carbon pools, GHG emissions reduction in energy and transport sector.	Development of dynamic maps characterizing water regime and soil bearing capacity. Acquiring of experimental data on results of implementation of water regime adopted soil regeneration methods and outputs of low grade biomass for biofuel production.

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	water maps can also be used to improve planning of forest operations to reduce cost and fuel consumption during harvesting and forwarding of logs and biofuel.			
Increase efficiency of utilization of timber – less biofuel and pulpwood and more harvested wood products with long half-life period	Investments into modern technologies allowing better planning of utilization of roundwood at sawmills to reduce proportion of energy wood and pulpwood, as well as technologies contributing to utilization of low grade deciduous logs. The measure contributes to increase of removals in HWP.	All forests without management restrictions.	HWP	Implementation potential of new technologies and new biomass products; development of new harvest planning and timber processing technologies
More efficient harvesting technologies to reduce timber damages (more sensitive feed rollers, operations adopted machines)	Utilization of sensitive feed rollers and more advanced regulation of pressure of delimbing knives and feed rollers lead to reduction of mechanical damages like imprints in logs, which significantly reduces share of biofuel (shawings) in sawmills, e.g. pole or veneer production. This measure is aimed at increase of removals in HWP.	All forests without management restrictions.	HWP	Development of work methods and automation solutions compensating lack of professional skills of less experienced operators and improving work conditions for experienced operators. Substantiation of economic advantages of sensitive feed rollers in production of different assortments.
Introduction of low impact logging technologies to avoid formation of methane hotspots and distribution of root rot and to ensure forest regeneration	Implementation of harvesting technologies reducing negative impact to forest soil, like compaction and ruts formation, which can lead to increase of CH_4 emissions in poorly aerated areas and reduction of forest growth potential. The measure overlaps with other measures aimed at improvement of water regime; however, in this case the solution for improvement of water regime is introduction of more sensitive harvesting technologies, particularly, use of excavator tracks or tracked forwarders in hauling of logs, or compact-class forwarders which are able to use better pathways in surrounding stands. The measure is mainly affecting growth	All forests without management restrictions.	All carbon pools and CH_4 emissions from soil.	Development and implementation of decision support tools for dynamic evaluation of soil bearing capacity and selection of appropriate forwarding method and equipment. Evaluation of the potential impact of the measure on forest growth and soil GHG emissions. Identification of typical problematic conditions, where CH_4

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	potential of forests, therefore it is contributing to all carbon pools and CH_4 emissions from soils. The measure is important to ensure forest regeneration in soils with low bearing capacity and sites not accessible for conventional harvesting technologies.			emissions can be avoided by use of appropriate forwarding method.
Improved algorithms creating bucking instructions and laser scanning and image analysis technologies to improve output of assortments	Bucking quality is one of the most important parameter determining output of HWP. Improvement and automation of bucking instructions, for instance, by application of machine learning methods, laser scanning and image analysis technologies can significantly improve output of logs applicable for production of HWP with long half-life.	All forest lands without management restrictions.	HWP	Development of methods and tools for improvement of bucking instructions using machine learning methods, laser scanning and image analysis tools; improved stand characteristics to provide better input for bucking projections.
Conversion of cropland to pastures or grassland for fodder production	Reduced tillage and fertilization leads to less active mineralization of organic substances in soil and less emissions of N_2O; however CH_4 emissions increases. Reduction of N_2O emissions is accounted in agriculture sector. Measure may result in increase of CH_4 emissions.	Drained organic rich soils where decomposition of organic matter is dominant carbon turnover process.	Soil and N_2O emissions.	Impact on N_2O emissions and better data on CO_2 and CH_4 emissions, life cycle assessment of production transfer.
Reduced tillage to avoid GHG emissions and carbon losses due to wind erosion	Reduced tillage may reduce CO_2 emissions from soil, however CH_4 emissions may increase. Data on impact on N_2O emissions are insufficient.	Croplands on organic soils	Soil carbon pool	GHG emission factors, transfer period, land use and soil properties including soil maps.
Non-woody energy crops, e.g. reed canary grass, in cropland and grassland	The measure is similar to conversion of cropland to grassland or pastures, however considers use of fertilizers and periodic tillage. The most of the emission reduction potential appears in energy sector.	Cropland and grassland on organic soil with no management restrictions and suitable for mechanic processing.	Living biomass, replacement effect in energy sector.	GHG emission factors, tools for assessment of applicability of the measure, soil maps; energy sector demand.
Rewetting of grassland – conversion to wetlands, to avoid CO_2 emissions	Rewetting can reduce CO_2 emissions from soil; however CH_4 and N_2O emissions may increase. Special treatment like removal of topsoil layer may	Grassland or cropland where rewetting is technically and economically the most feasible	Soil carbon pool.	Preconditions for implementation of the measure, emission factors

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	be necessary to reduce CO_2 emissions. In flat terrain impact on surrounding areas should be considered.	option.		and transition period.
Increase of use of legumes to reduce N_2O emissions	Avoiding of mineral fertilizers can reduce N_2O emissions from soil.	Croplands on organic soils suitable for crop production.	N_2O emissions	Impact on N_2O emissions in comparison to conventional management procedures; optimization of rotations; integration with non-conventional soil scarification methods, e.g. reduced tillage.
Adjust fertilizer application rates and timing in croplands to reduce N_2O emissions	The measure contributes to reduction of application on N fertilizers, thus reducing N_2O emissions from soil.	Croplands on organic soils suitable for crop production.	N_2O emissions	Impact on N_2O emissions in comparison to conventional management procedures.
Application of nitrification inhibitors to reduce N_2O emissions	Inhibitors of N_2O emissions reduces direct and indirect N_2O emissions due to application of mineral fertilizers.	Croplands on organic soils suitable for crop production.	N_2O emissions	Impact on GHG emissions in organic soils.
Introduction of agroforestry systems to increase carbon storage	Agroforestry systems considers production of farm crops, e.g. cereals, fodder or protein crops gradually replaced by woody crops. Implementation of the measure will contribute to increase of carbon stock in soil and other carbon pools providing at the same time more significant economic benefits than conventional afforestation.	Croplands and grasslands on drained organic soils suitable for crop production.	All carbon pools, substantiation effect in energy sector.	Methodologies for assessment of climate change mitigation potential needs to be developed.
Optimize grassland management (species introduction, increase of lifespan of grasslands, increase of productivity)	Optimized management systems can contribute to increased removals of CO_2 in living biomass and soil carbon stock.	Grasslands on organic soils	Soil carbon pool	Development of methodologies for verification of climate change mitigation effect and optimization of management of grasslands.
Adaptation of drainage systems to optimal depth of groundwater and outflows –	Fluctuations of groundwater level is known reason for increase of CH_4 emissions, therefore regulation of groundwater level can ensure reduction of CH_4	Drained organic soils	CH_4 and DOC emissions.	Elaboration of methodologies for climate change mitigation

Title	Substantiation of the impact	Criteria for site selection	Addressed carbon pools and GHG emissions	Knowledge gaps to be filled, uncertainties, collaboration needed
to avoid CH_4 emissions and to reduce CO_2 and DOC emissions	emissions.			assessment and optimization of technologies for adaptation of drainage systems to reduce GHG emissions.
Buffer zones alongside to drainage systems to compensate CO_2 emissions, to reduce nutrients leaching and DOC emissions	Buffer zones are known for high growth potential, thus contributing to CO_2 removals in living biomass and other carbon pools. Leaching nutrients from croplands ensures additional CO_2 removals.	Drained organic soils with open drainage systems.	All carbon pools, DOC emissions.	Evaluation of the climate change mitigation effect and development of buffer zone management solutions. Decision support tools for establishment and management of buffer zones.

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