REPORT

ON IMPLEMENTATION OF THE PROJECT

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

WORK PACKAGE

TOOLS FOR MODELLING OF IMPACT OF CLIMATE CHANGE ON GHG EMISSIONS (C.2)

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

SUMMARY

The project activity deliverable C.2.4. underlines and demonstrates developed mathematical tools for elaboration of projections of GHG emissions under different climatic conditions and activity data for projections of GHG emissions from organic soils and the preliminary results obtained from the SUSI-simulator runs, where significant inconsistencies between actual measurements were estimated, therefore it was decided to not continue developing SUSI-simulator for this action. This final report is targeted on presentation of calculation tool "SEG modelis" developed for GHG emissions and removals projection from different land uses and different climatic conditions applied, taking into account regional emission factors developed during the C1 action. Report also presents comparison of the projected GHG emissions and removals balance estimated applying different climate change mitigation measures/scenarios.

Selected and elaborated toolsets – spreadsheet model tool "SEG modelis" and SUSI peatland simulator, were further tested and developed during the implementation of activity C2.4. After the first runs of SUSI-simulator with projected climate data and country specific forest stand data, serious issues of the overestimation of ground water level occurred and several solutions tried were not effective to obtain results compatible with actual field measurements data, therefore it was decided to not further elaborate SUSI-simulator and continue working with spreadsheet calculation tool "SEG modelis". "SEG modelis" was developed to cover all climate change mitigation measures analysed during action C3. Country specific data prepared to run SUSI-simulator was adjusted to use in "SEG modelis" – stand growth, harvest and mortality figures, climate projections (projected monthly averages of temperature). In order to Selected and elaborated toolsets – spreadsheet model "SEG modelis" w and updated during the implementation of activity C.2.4. Spreadsheet model tool offers non-spatial modeling of peatland soil forest stand development and GHG emissions as well as GHG emissions and removals in non-forest land in peatland (introduction of legumes into cropping system, conversion from cropland to grassland, paludiculture, etc.), based on emission factors developed during LIFE OrgBalt and available field data.

Report includes examples of SUSI peatland simulator outcomes with country specific data (Lithuania) indicating issues with the model and projections of GHG emissions from organic soils in forest and other land uses prepared by the spreadsheet tool "SEG modelis".

ABBREVIATIONS

CCM – climate change mitigation

CH_4 – methane

CO_2 – carbon dioxide

GHG – greenhouse gas

LAMMC – Lietuvos agrarinių ir miškų mokslų centras (Lithuanian Research Centre for Agriculture and Forestry)

LSFRI "Silava" – Latvian State Forest Research Institute "Silava"

LUKE – Natural Resources Institute Finland

UEF – University of Eastern Finland

N_2O – nitrous oxide

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1. SUSI peatland simulator testing

Development and testing of SUSI peatland simulator has continued nearly to the end of the project Action C2, however, reliable projection results were not obtained after country specific data was used as input for the model.

Baltic partners (modellers from all Baltic states) continued working on acquiring data used by the model, with several remote meetings. Coding and model adjustment issues were administered by the model developers in LUKE/UEF. Model runs with projected climate data, prepared for each Baltic country, was also administered by the model developers in LUKE/UEF.

The outcomes of the SUSI peatland simulator are focused on forest stand growth scenarios, ground water depth modelling and calculation of annual CO_2 efflux during the modeled time period, applying nutrient availability and daily weather conditions. However, as mentioned, issues with the modelling outcomes were detected: significant overestimation of the groundwater level, which, in turn, affects the projection of GHG emissions from soil (Fig. 1).

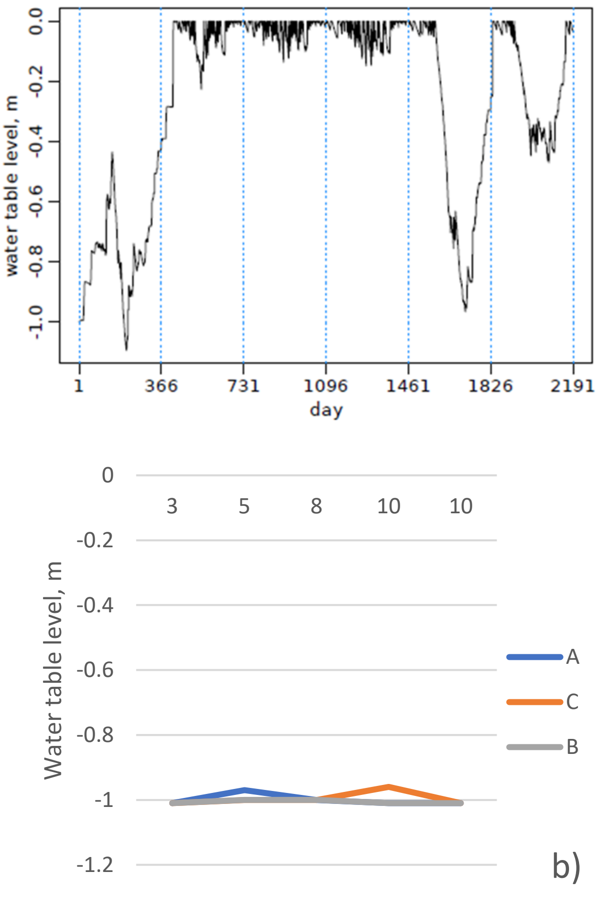

Fig. 1. Water table level projection for birch stand in Lithuania and actual water table level measurements for the corresponding demo site (part b): A – 25 m, B – 50 m, C – 75 m distance from

ditch

As it can be seen from the simulation example in Fig. 1 (example from simulation with Lithuanian country specific stand and climate projection data), the predicted water table is very close to the soil surface most of the year, even for rainy years. The projected water table level is compared to the actual water table level estimation in the particular reference site in Lithuania (Fig. 1, part b). The reasons behind this could be the very large strip (distance between ditches) width in Lithuania, compared to Finnish conditions or the impact of slope, when some surface runoff might be reducing water table level. It was decided to try modelling with slope introduced, applying 3m per 100 m slope to the simulation. However, such an adjustment did not provide significant difference in the results (Fig. 2) and larger slope application was not possible at all.

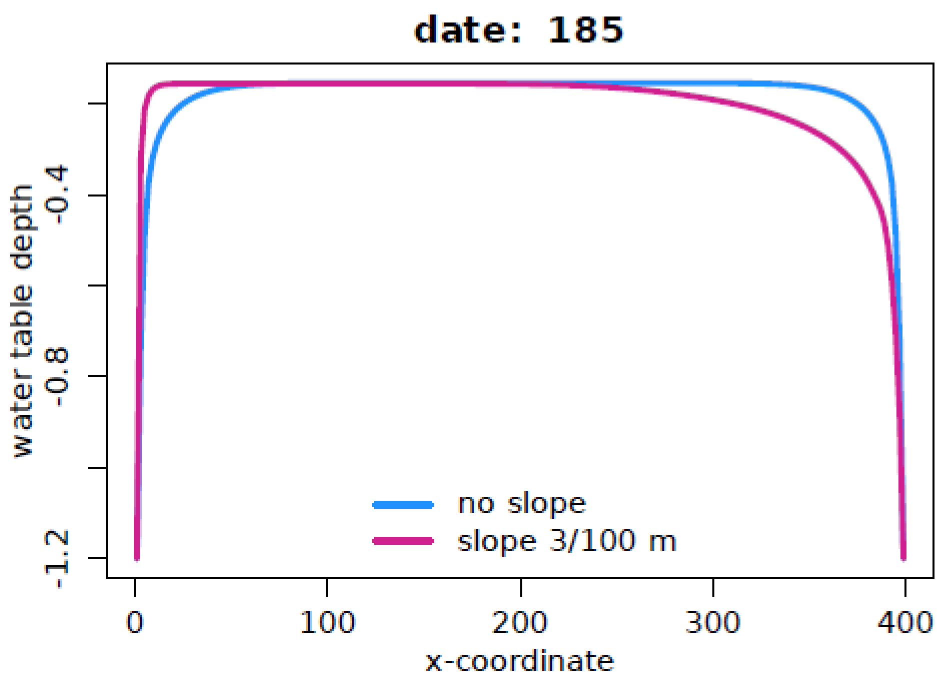

Fig. 2. Comparison of the SUSI simulation results with no slope and 3m per 100 m slope applied for projection of GHG emissions and removals balance in Lithuanian forest stand

There are other factors that could affect soil water balance, especially soil density and evapotranspiration, but due to the model being designed specifically for Finnish conditions, it was decided that it might take too long to try to change model specifications closely to Baltic countries conditions and the plausibility of the results is not guaranteed. Therefore it was decided to shift from SUSI simulator development to solely the development of spreadsheet tool, which can cover different land uses together and provide accurate comparison of different land use management scenarios impact to GHG emissions and removals balance.

2. Development of spreadsheet tool "SEG modelis"

Spreadsheet tool "SEG modelis" consists of all carbon sinks and pools, as required for national greenhouse gas inventory report under the 2006 IPCC Guidelines, adopted by the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (2.CMP/7), C ha^{-1}:

- Carbon stock changes in living biomass;
- Carbon stock changes in soil;
- Carbon stock changes in dead wood (for forest land);
- Carbon stock changes in litter (For forest land);
- Carbon stock changes in harvested wood products (HWP, for forest land only).

And additionally to the requirements:

- GHG emissions from soil due to the heterotrophic respiration (CO_2);
- GHG emission saving due to the substitution effect (natural gas substitution with woody biomass).

  Additionally to the carbon stock changes and GHG emission savings, preliminary evaluation of implementation costs are also available (Eur ha^{-1}).

Main input data to the spreadsheet tool, common for all countries:

- Assortment structure for HWP with production losses
- Production of assortments during different management actions (thinning, regenerating)
- Biomass equations with coefficients
- Polynomial equations for carbon inputs from woody litter, non-woody litter, carbon stock in non-woody plants, dead wood, sawnwood, platewood, paper and paperboard
- Assortment values
- Cost of management practices (soil preparation, seedlings, maintenance of drainage, etc.)

Country specific input data (if available):

- Forest stand data – age, height, diameter, basal area, N of living, harvested and dead trees
- Temperature projections (correlation with CO_2)
- Carbon stock in litter, carbon stock in agricultural biomass, soil carbon input ir agricultural land (due to decay of biomass)
- EFs for both drained and not drained (wet) conditions: CH_4, N_2O, CO_2 (heterotrophic respiration) + dissolved organic carbon (DOC).

3. Common and country specific data included in projections

All parameters in the model are selectable for 5 countries of regions including general assumptions for boreal and temperate climate region. The most of the parameters in the default version of the model are the same for all regions, and can be updated during the adaptation of the model to different conditions.

Table 1 in the sheet [1] shows approximate structure of assortments from roundwood (sawn-wood, plate-wood, bark and processing residues) in thinning and final felling. Species are linked to sheet [3]. Losses of harvesting residues is parameter used in the calculation if it is considered to extract harvesting residues for biofuel production. In sheet [1] it is also possible to determine output of pulp from volume of pulpwood. The default value is 50%.

Table 1. Assortments' structure in harvest stock

Dominant species	Water regime	Felling type	Share of sawn materials from logs	Proportion of platewood	Proportion of bark from roundwood	Proportion of processing residues	Losses of harvesting residues
Spruce	Drained	Thinning	25%	25%	11%	50%	50%
Spruce	Wet	Thinning	25%	25%	11%	50%	50%
Pine	Drained	Thinning	25%	25%	11%	50%	50%
Pine	Wet	Thinning	25%	25%	11%	50%	50%
Birch	Drained	Thinning	25%	25%	11%	50%	50%
Birch	Wet	Thinning	25%	25%	11%	50%	50%
Hybrid poplar	Drained	Thinning	25%	25%	11%	50%	50%
Hybrid poplar	Wet	Thinning	25%	25%	11%	50%	50%
Aspen	Drained	Thinning	25%	25%	11%	50%	50%
Aspen	Wet	Thinning	25%	25%	11%	50%	50%
Black alder	Drained	Thinning	25%	25%	11%	50%	50%
Black alder	Wet	Thinning	25%	25%	11%	50%	50%
Spruce	Drained	Final felling	25%	25%	10%	50%	30%
Spruce	Wet	Final felling	25%	25%	10%	50%	30%
Pine	Drained	Final felling	25%	25%	10%	50%	30%
Pine	Wet	Final felling	25%	25%	10%	50%	30%
Birch	Drained	Final felling	25%	25%	11%	50%	30%
Birch	Wet	Final felling	25%	25%	11%	50%	30%
Hybrid poplar	Drained	Final felling	25%	25%	11%	50%	30%
Hybrid poplar	Wet	Final felling	25%	25%	11%	50%	30%
Aspen	Drained	Final felling	25%	25%	11%	50%	30%
Aspen	Wet	Final felling	25%	25%	11%	50%	30%
Black alder	Drained	Final felling	25%	25%	11%	50%	30%
Black alder	Wet	Final felling	25%	25%	11%	50%	30%

Sheet [2] sets coefficients for polynomial equations for calculation of output of roundwood assortments based on average volume and species of extracted trees. The nomenclature of the assortments is based on the nomenclature used in the Joint stock company "Latvia's state forests" (AS 'Latvijas valsts meži', 2010). The prediction model is based on the harvester data.

Here in this sheet it is also possible to set cost of assortment and forest biofuel. The default values are provided in Table 2. Cost of management activities associated with implementation of the measures in forest lands can also be updated in sheet [2]. Default values are provided in Table 3. The most of the values are based on the publications of the National statistical bureau.

Table 2. Value of assortment

Assortment	Unit	Value, €
10-13,9	€ m^{-3}	57.0
12-17,9	€ m^{-3}	61.0
14-17,9	€ m^{-3}	65.0
18-23,9	€ m^{-3}	72.0
18-27,9	€ m^{-3}	60.0
24<	€ m^{-3}	79.0
28<	€ m^{-3}	86.0
6-9,9	€ m^{-3}	53.0
A 28<	€ m^{-3}	94.0
FIA 18<	€ m^{-3}	73.0
FIB 18<	€ m^{-3}	74.0
Firewood	€ m^{-3}	34.0
Pulpwood 7-49,9	€ m^{-3}	63.0
Long poles 18<	€ m^{-3}	75.0
Low grade logs 18<	€ m^{-3}	66.0
Wood chip	€ LV m^{-3}	20.0

Table 3. Cost of management activities

Type	Unit	Value
Soil scarification	€ ha^{-1}	450.0
Seedlings	€ ha^{-1}	426.0
Long cuttings	€ ha^{-1}	1200.0
Short cuttings	€ ha^{-1}	1200.0
Planting	€ ha^{-1}	151.1
Mechanized planting	€ ha^{-1}	700.0
Tending	€ ha^{-1}	144.7
Pre-commercial thinning	€ ha^{-1}	157.2
Harvest in commercial thinning	€ m^{-3}	9.9
Harvest in regenerative felling	€ m^{-3}	7.1
Forwarding in thinning	€ m^{-3}	6.4

Type	Unit	Value
Forwarding in regenerative felling	€ m^{-3}	4.9
Production of harvesting residues	€ ton^{-1}	4.9
Road transport	€ m^{-3}	6.5
Application of mineral fertilizers	€ ha^{-1}	350.0
Application of wood ash	€ ha^{-1}	120.0
Establishment of drainage systems[1]	€ ha^{-1}	1500.0
Maintenance of drainage systems	€ ha^{-1} yr^{-1}	25.0
Administration	% of total costs	7%

Sheet [3] is the most important for calculation of GHG emissions from soil. Table 4 shows the main species and moisture conditions based calculation parameters in forest land. The main parameters for non-forest lands are provided in Table 5. Additionally for strip felling in pine stands with drained peat soils it is assumed in the model that net removals of CH_4 increases by 23% and CO_2 emissions reduces by 1% during the rotation period.

Table 4. Emissions factors for organic soils in forest lands

Dominant species	Water regime	Average wood density, tons m^{-3}	Carbon content in wood, tons ton^{-1}	Dead wood turnover period, years	CH_4 emission factor for ditches, kg CH_4 ha^{-1} yr^{-1}	Proportion of ditch area	CH_4 emission factor, kg CH_4 ha^{-1} yr^{-1}	N_2O emission factor, kg N_2O ha^{-1} yr^{-1}	DOC emission factor, tons CO_2 ha^{-1} yr^{-1}	Average carbon stock in litter, tons C ha^{-1}	Period to reach steady stage, years
Spruce	Drained	0.4	0.5	40.0	217.0	0.0	-4.8	9.4	1.1	2.9	150.0
Spruce	Wet	0.4	0.5	40.0	0.0	0.0	15.5	1.8	0.9	21.3	150.0
Pine	Drained	0.4	0.5	40.0	217.0	0.0	-4.8	2.5	1.1	19.7	150.0
Pine	Wet	0.4	0.5	40.0	0.0	0.0	51.1	3.0	0.9	6.7	150.0
Birch	Drained	0.5	0.5	20.0	217.0	0.0	-4.8	18.1	1.1	2.6	150.0
Birch	Wet	0.5	0.5	20.0	0.0	0.0	62.8	3.6	0.9	6.7	150.0
Aspen	Drained	0.5	0.5	20.0	217.0	0.0	-4.8	13.9	1.1	2.6	150.0
Aspen	Wet	0.5	0.5	20.0	0.0	0.0	51.1	3.0	0.9	6.7	150.0
Hybrid poplar	Drained	0.5	0.5	20.0	217.0	0.0	-4.8	13.9	1.1	1.0	150.0
Willow	Drained	0.5	0.5	20.0	217.0	0.1	-4.8	13.9	1.1	2.6	5.0
Black alder	Drained	0.5	0.5	20.0	217.0	0.0	-4.8	34.3	1.1	21.0	150.0
Black alder	Wet	0.5	0.5	20.0	0.0	0.0	59.0	2.9	0.9	2.9	150.0

Table 5. Emissions factors for organic soils in non-forest land

1 https://www.diva-portal.org/smash/get/diva2:1020388/FULLTEXT01.pdf

Land use	Management	Water regime	Carbon stock at a steady stage, tons C ha^{-1}		Rotation period	Soil carbon input, tons C ha^{-1} yr^{-1}			Proportion of ditch area	CH_4 emission factor for ditches, kg CH_4 ha^{-1} yr^{-1}	CH_4 emission factor, kg CH_4 ha^{-1} yr^{-1}	N_2O emission factor, kg N_2O ha^{-1} yr^{-1}	DOC emission factor, tons CO_2 ha^{-1} yr^{-1}
			above ground	below ground		above ground	below ground	fine root					
Cropland	Conventional	Drained	4.4	0.9	1.0	2.7	0.6	0.3	5%	1165.0	-1.1520	10.5084	1.1367
Cropland	Conventional with legumes	Drained	3.6	0.7	3.0	2.8	0.5	0.2	5%	1165.0	2.0852	10.5084	1.1367
Cropland	Organic farming	Drained	3.6	0.7	1.0	2.8	0.5	0.2	5%	1165.0	-1.1520	10.5084	1.1367
Cropland	Cranberry field	Wet	2.5		3.0	2.5			5%	542.0	6.2576	0.3500	0.8800
Cropland	Blueberry field	Wet	5.0	2.5	5.0	2.5		1.3	5%	542.0	27.580	1.0800	1.1367
Wetland	Peat extraction	Drained	0.0	0.0	0.0				5%	542.0	12.110	0.6700	1.1367
Wetland	Restored wetland	Wet	6.8			1.9					133.225	0.7594	0.8800
Grassland	Fodder production	Drained	3.2	1.2	1.0	0.9	0.5	0.7	5%	1165.0	-1.5275	6.3427	1.1367
Grassland	Regulated groundwater	Drained	3.2	1.2	1.0	0.9	0.5	0.7	5%	1165.0	2.6963	6.3053	1.1367
Grassland	Rewettwed	Wet	3.2	1.2	1.0	0.9	0.5	0.7			32.1923	-0.0113	
Grassland	Pastures	Drained	6.8		1.0	0.9	0.5	0.7	5%	1165.0	2.6963	0.5029	1.1367

GHG equivalent for CH_4 in the calculation is 28 and for N_2O 265 according to the (Edenhofer, 2014).

Coefficients for calculation of woody biomass is provided for above-ground biomass, stem biomass, branch biomass and below-ground biomass for all species listed in sheet [3] except willows, for which biomass is calculated separately using cone formula. The default factors based on (Liepiņš et al., 2017, 2021) are provided in Table 6. Following formula (No. **Error! Reference source not found.**) is used for calculation of all types of woody biomass.

$$\text{Biomass (kg)} = k \times \exp\left(a + b \times \left(\frac{D}{D+m}\right) + c \times H + d \times \ln(H) + e \times \ln(D)\right) \qquad (1)$$

Table 6. Biomass coefficients in forests

Dominant species	Biomass	a	b	c	d	e	m	k
Spruce	AGB	-0.5244	8.8563	0.0000	0.3879	0.0000	19.0000	1.0127
Spruce	SB	-2.5842	7.0769	0.0232	0.9631	0.0000	15.0000	1.0022

Dominant species	Biomass	a	b	c	d	e	m	k
Spruce	BB	0.3300	12.0986	0.0000	-1.0682	0.0000	16.0000	1.0121
Spruce	BGB	-2.4967	10.8184	0.0000	0.0000	0.0000	14.0000	1.0388
Pine	AGB	-1.4480	8.7399	0.0000	0.5624	0.0000	16.0000	1.0086
Pine	SB	-2.8125	7.1368	0.0118	1.1270	0.0000	15.0000	1.0053
Pine	BB	-1.6032	14.7696	0.0000	-1.5888	0.0000	11.0000	1.0415
Pine	BGB	-3.2937	9.0334	0.0000	0.5353	0.0000	14.0000	1.0350
Birch	AGB	-2.1284	9.3375	0.0221	0.2838	0.0000	11.0000	1.0041
Birch	SB	-2.9281	8.2943	0.0184	0.7374	0.0000	11.0000	1.0020
Birch	BB	-1.0091	16.9249	0.0000	-2.0462	0.0000	12.0000	1.0745
Birch	BGB	-3.6432	0.0000	0.0000	0.0000	2.5127	0.0000	1.0060
Hybrid poplar	AGB	-1.9434	9.7506	0.0337	0.0000	0.0000	11.0000	0.9900
Hybrid poplar	SB	-2.8955	8.3896	0.0226	0.6148	0.0000	11.0000	1.0058
Hybrid poplar	BB	-2.3703	14.3352	0.0000	-1.0849	0.0000	12.0000	1.0040
Hybrid poplar	BGB	-2.3114	10.3644	0.0000	0.0000	0.0000	15.0000	0.9917
Aspen	AGB	-1.9434	9.7506	0.0337	0.0000	0.0000	11.0000	0.9900
Aspen	SB	-2.8955	8.3896	0.0226	0.6148	0.0000	11.0000	1.0058
Aspen	BB	-2.3703	14.3352	0.0000	-1.0849	0.0000	12.0000	1.0040
Aspen	BGB	-2.3114	10.3644	0.0000	0.0000	0.0000	15.0000	0.9917
Grey alder	AGB	-2.2207	9.7183	0.0336	0.0000	0.0000	10.0000	1.0051
Grey alder	SB	-2.6141	9.0687	0.0576	0.0000	0.0000	9.0000	0.9934
Grey alder	BB	-2.3445	17.3595	0.0000	-2.2770	0.0000	9.0000	1.0791
Grey alder	BGB	-2.9585	0.0000	0.0000	0.0000	2.1141	0.0000	1.0142
Black alder	AGB	-1.6846	9.3412	0.0221	0.2489	0.0000	14.0000	0.9962
Black alder	SB	-2.4428	8.4713	0.0295	0.5315	0.0000	13.0000	1.0069
Black alder	BB	-0.4283	15.6239	0.0000	-1.9661	0.0000	15.0000	1.0262
Black alder	BGB	-2.6672	0.0000	0.0000	0.0000	2.1004	0.0000	1.0145

Carbon input with woody litter is calculated using species specific polynomial equation. Upper limit for the carbon input is set according to the basal area threshold values (Bārdule et al., 2021). Calculation formula (No. **Error! Reference source not found.**) is provided below. G is basal area expressed as m^2 ha^{-1}. Default coefficients are provided in Table 7.

$$C_{litter} \text{ (tonnes C ha}^{-1}\text{ yr}^{-1}) = G^4 \times a + G^3 \times b + G^2 \times c + G \times d + e \quad (2)$$

Table 7. Carbon input with woody litter

Dominant species	a	b	c	d	e	Max value
Spruce	-0.000008	0.000542	-0.011340	0.190236	0.000000	30.0
Pine	-0.000014	0.000969	-0.021880	0.245253	0.000000	30.0
Birch	-0.000015	0.000546	-0.000466	0.069636	0.000000	26.0
Aspen	-0.000015	0.000546	-0.000466	0.069636	0.000000	26.0

Dominant species	a	b	c	d	e	Max value
Hybrid poplar	-0.000015	0.000546	-0.000466	0.069636	0.000000	26.0
Willow	-0.000015	0.000546	-0.000466	0.069636	0.000000	26.0
Black alder	-0.000015	0.000546	-0.000466	0.069636	0.000000	26.0

Carbon input with non-woody litter in forest land is calculated using species specific polynomial equation. Upper limit for the carbon input is set according to the basal area threshold values. Calculation formula (No. **Error! Reference source not found.**) is provided below. G is basal area expressed as m^2 ha^{-1}. Default coefficients are provided in Table 8.

$C_{non-woody\ litter}$ (tonnes C ha^{-1} yr^{-1}) = $G^4 \times a + G^3 \times b + G^2 \times c + G \times d + e$ (3)

Table 8. Carbon input with non-woody litter

Dominant species	a	b	c	d	e	Max value
Spruce	0.000027	-0.002093	0.057749	-0.663115	3.183354	30.0
Pine	0.000011	-0.001056	0.035375	-0.496942	3.194996	30.0
Birch	0.000017	-0.001394	0.042332	-0.575063	3.268113	26.0
Aspen	0.000017	-0.001394	0.042332	-0.575063	3.268113	26.0
Hybrid poplar	0.000017	-0.001394	0.042332	-0.575063	3.268113	26.0
Willow	0.000017	-0.001394	0.042332	-0.575063	3.268113	26.0
Black alder	0.000017	-0.001394	0.042332	-0.575063	3.268113	26.0

Carbon stock in dead wood in forest land is calculated using species and basal area specific polynomial equation. This parameter is not calculated in afforested lands, and it is used only to determine initial carbon stock in dead wood. Upper limit for the carbon input is set according to the basal area threshold values. Calculation formula (No. **Error! Reference source not found.**) is provided below. G is basal area expressed as m^2 ha^{-1}. Default coefficients are provided in Table 9. Default carbon stock values are calculated on the base of the model run for two generations of trees of the same species or at least 180 years long period.

$C_{deadwood}$ (tonnes C ha^{-1} yr^{-1}) = $G^4 \times a + G^3 \times b + G^2 \times c + G \times d + e$ (4)

Table 9. Carbon stock in dead wood in managed forests

Dominant species	a	b	c	d	e
Spruce	0.000424	-0.030501	0.710823	-7.083432	93.865713
Pine	0.000037	-0.006855	0.270987	-3.903290	61.217237
Birch	0.000178	-0.013469	0.312192	-2.664939	18.727676
Aspen	0.000178	-0.013469	0.312192	-2.664939	18.727676
Hybrid poplar	0.000178	-0.013469	0.312192	-2.664939	18.727676
Willow	0.000000	0.000000	0.000000	0.000000	0.000000
Black alder	0.000178	-0.013469	0.312192	-2.664939	18.727676

Carbon stock in dead wood in forest land is calculated using species and basal area specific polynomial equation. This parameter is not calculated in afforested lands, and it is used only to determine initial carbon stock in dead wood. Upper limit for the carbon input is set according to the basal area threshold values. Calculation formula (No. **Error! Reference source not found.**) is provided below. G is basal area expressed as m^2 ha^{-1}. Default coefficients are provided in Table 9. Default carbon stock values are calculated on the base of the model run for two generations of trees of the same species or at least 180 years long period.

$C_{deadwood}$ (tonnes C ha^{-1} yr^{-1}) = $G^4 \times a + G^3 \times b + G^2 \times c + G \times d + e$ (5)

Initial carbon stock in HWP in calculated using linear regression equation (No. **Error! Reference source not found.**) depending from basal area and dominant species (G expressed as m^2 ha^{-1}). Coefficients for equation No. **Error! Reference source not found.** for sawnwood are provided in Table 10, for platewood – in Table 11, for pulpwood – in Table 12. Default carbon stock values are calculated on the base of the model run for two generations of trees of the same species or at least 180 years long period.

C_{HWP} (tonnes C ha^{-1} yr^{-1}) = $G \times a + e$ (6)

Table 10. Carbon stock in sawnwood (5.C & 5.NC) in managed forests

Dominant species	a	b
Spruce	-0.437336	20.840077
Pine	-0.476845	22.100373
Birch	-0.304579	12.090044
Aspen	-0.096996	4.826518
Hybrid poplar	-0.145217	29.000000
Black alder	-0.304579	12.090044

Table 11. Carbon stock in platewood (6 1, 6 2, 6 3, 6.4.1, 6.4.2, 6.4.x, 6.4.3) in managed forests

Dominant species	a	b
Spruce	-0.420516	20.038535
Pine	-0.458505	21.250359
Birch	-0.292864	11.625042
Aspen	-0.093266	4.640883
Hybrid poplar	-0.139632	28.011337
Black alder	-0.292864	11.625042

Table 12. Carbon stock in paper and cardboard (10) in managed forests

Dominant species	a	b
Spruce	-0.008311	0.403860
Pine	-0.344292	1.253129
Birch	-1.495479	4.966780
Aspen	-0.805852	2.326979
Hybrid poplar	0.000000	0.000000

Dominant species	a	b
Black alder	0.000000	0.000000

Default parameters are provided in the model till 2050. For the period after 2050 static values from 2050 are used.

Sheet [4] of the model contains information about the forest growth. It covers 200 years period assuming that every next generation repeats growth rate of the previous generation. Different growth rates are provided depending from dominant species, moisture conditions, treatment (selective felling, fertilization). Parameters determined in the calculation are site index, A – age in years, H – average tree height in m, D – average tree diameter in cm, G – basal are as $m^2\ ha^{-1}$, N – number of living trees per ha^{-1}, M – growing stock as $m^3\ ha^{-1}$, Incr. – potential increment of living trees in $m^3\ ha^{-1}\ yr^{-1}$, Hnoc – height of average extracted tree in m, Dnoc – diameter of average extracted tree in cm, Gnoc – basal area of extracted tree in $m^2\ ha^{-1}$, Nnoc – number of extracted trees per ha^{-1}, Mnoc – harvested stock in $m^3\ ha^{-1}$, Hatm – height of average diseased tree in m, Datm – diameter of average diseased tree in cm, Gatm – basal area of diseased trees in $m^2\ ha^{-1}\ yr^{-1}$, Natm – number of diseased trees per $ha^{-1}\ yr^{-1}$, Matm – stock of diseased trees in $m^3\ ha^{-1}\ yr^{-1}$.

Model calculations are unified for non-forest land scenarios and forest land, including afforestation, scenarios.

4. GHG emission factors applied for projections

GHG emissions (CH_4, N_2O) emissions from drained or wet organic soils in forest and non-forest land are estimated with emission factors (EF, Tables 13 & 14), combined from LIFE OrgBalt project results and default values from IPCC 2006 Guidelines. Calculation formula for both forest and non-forest land is provided below (No. 7).

$$GHG\ emissions_{drained/wet} = A_{drained/wet} \cdot EF_{drained/wet} \quad (7)$$

$A_{drained/wet}$ – area of drained or wet organic soil, ha (taking into account share of drainage ditches (for CH_4 estimation));
$EF_{drained/wet}$ – GHG emission factor (CH_4, N_2O).

Table 13. Emission factors for GHG emissions from organic soil in forest land

Dominant species	Water regime	CH_4 emission factor for ditches, kg CH_4 $ha^{-1}\ yr^{-1}$	Proportion of ditch area	CH_4 emission factor, kg CH_4 $ha^{-1}\ yr^{-1}$	N_2O emission factor, kg N_2O $ha^{-1}\ yr^{-1}$	DOC emission factor, tonnes CO_2 $ha^{-1}\ yr^{-1}$
Spruce	Drained	217.0	0.0	-4.8	9.4	1.1
Spruce	Wet	0.0	0.0	15.5	1.8	0.9
Pine	Drained	217.0	0.0	-4.8	2.5	1.1
Pine	Wet	0.0	0.0	51.1	3.0	0.9
Birch	Drained	217.0	0.0	-4.8	18.1	1.1

Birch	Wet	0.0	0.0	62.8	3.6	0.9
Aspen	Drained	217.0	0.0	-4.8	13.9	1.1
Aspen	Wet	0.0	0.0	51.1	3.0	0.9
Hybrid poplar	Drained	217.0	0.0	-4.8	13.9	1.1
Willow	Drained	217.0	0.1	-4.8	13.9	1.1
Black alder	Drained	217.0	0.0	-4.8	34.3	1.1
Black alder	Wet	0.0	0.0	59.0	2.9	0.9

Table 14. Emission factors for GHG emissions from organic soil in forest land

Land use	Management	Water regime	Proportion of ditch area	CH_4 emission factor for ditches, kg CH_4 ha^{-1} yr^{-1}	CH_4 emission factor, kg CH_4 ha^{-1} yr^{-1}	N_2O emission factor, kg N_2O ha^{-1} yr^{-1}	DOC emission factor, tonnes CO_2 ha^{-1} yr^{-1}
Cropland	Conventional	Drained	5%	1165.0	-1.1520	10.5084	1.1367
Cropland	Conventional with legumes	Drained	5%	1165.0	2.0852	10.5084	1.1367
Cropland	Organic farming	Drained	5%	1165.0	-1.1520	10.5084	1.1367
Cropland	Cranberry field	Wet	5%	542.0	6.2576	0.3500	0.8800
Cropland	Blueberry field	Wet	5%	542.0	27.5800	1.0800	1.1367
Wetland	Peat extraction	Drained	5%	542.0	12.1100	0.6700	1.1367
Wetland	Restored wetland	Wet			133.2245	0.7594	0.8800
Grassland	Fodder production	Drained	5%	1165.0	-1.5275	6.3427	1.1367
Grassland	Regulated groundwater	Drained	5%	1165.0	2.6963	6.3053	1.1367
Grassland	Rewettwed	Wet			32.1923	-0.0113	
Grassland	Pastures	Drained	5%	1165.0	2.6963	0.5029	1.1367

Soil heterotrophic respiration is calculated using exponential equation (No. 8) and average monthly temperature values. Coefficients for the forest lands are provided in Table 15 and for the non-forest land – in Table 16.

$$Y = A \times \exp(B \times X) \tag{8}$$

Where:

Y – heterotrophic respiration, mg CO_2-C m^{-2} h^{-1}

X – average monthly temperature, °C

A, B – coefficients

Table 15. Factors for CO_2 emissions from soil in forest land

Dominant species	Water regime	A	B
Spruce	Drained	95.117710	0.055480
Spruce	Wet	36.195530	0.076470
Pine	Drained	74.754810	0.042220
Pine	Wet	74.911240	0.042210
Birch	Drained	83.622600	0.046360
Birch	Wet	84.771620	0.044140
Aspen	Drained	83.622600	0.046360
Aspen	Wet	84.771620	0.044140
Hybrid poplar	Drained	83.622600	0.046360
Willow	Drained	83.622600	0.046360
Black alder	Drained	83.622600	0.046360
Black alder	Wet	84.771620	0.044140

Table 16. Factors for CO_2 emissions from soil in non-forest land

Land use	Management	Water regime	A	B
Cropland	Conventional	Drained	59.269208	0.122268
Cropland	Conventional with legumes	Drained	59.269208	0.122268
Cropland	Organic farming	Drained	59.269208	0.122268
Cropland	Cranberry field	Wet	19.756840	0.100550
Cropland	Blueberry field	Wet	23.135080	0.105940
Wetland	Peat extraction	Drained	6.717880	0.138760
Wetland	Restored wetland	Wet	14.778340	0.117810
Grassland	Fodder production	Drained	68.256937	0.085210
Grassland	Regulated groundwater	Drained	85.648390	0.083230
Grassland	Rewettwed	Wet	58.156930	0.098220
Grassland	Pastures	Drained	68.256937	0.085210

4. Climate change mitigation scenarios analysed

The model is mainly based on the information acquired in LIFE OrgBalt study sites, except cranberry and blueberry plantations, which were measured during LIFE REstore project (Table 17). Effect of mitigation measures is determined by comparison of different scenarios listed in Table 17. List of implemented measures with references to the scenarios used to characterize initial and after-implementation conditions is provided in Table 18.

Table 17. Calculation scenario description

Sheet No	Sheet	Description
5	LVC101	Arable land where crops are grown (Lazdiņi)
6	LVC102	Grassland in reclaimed semi-hydromorphic soil (Rucava, 024-3-7)
7	LVC103	Lawn in reclaimed peat soil (Lazdiņi)

Sheet No	Sheet	Description
8	LVC114	Low marsh unaffected by economic activity (213-327-1)
9	LVC301	Transformation of arable land with drained organic soil into grassland (Andrupēni)
10	LVC304	The use of papilionaceous plants in plant rotation in arable land with improved organic soil (Lazdiņi, Slampe)
11	LVC305	Controlled drainage in grassland with drained organic soil (Vecauce)
12	Cranberries	Cranberry plantation in former peat extraction site (LIFE REstore sites)
13	Blueberries	Blueberry plantation in former peat extraction site (LIFE REstore sites)
14	LVC104	Medium-aged spruce stand with reclaimed peat soil (409-474-21)
15	LVC105	Spruce stand with reclaimed peat soil, where wood ash was spread at least 5 years ago (301-209-13)
16	LVC106	Control area in a spruce stand with reclaimed peat soil for characterizing the impact of ash use (301-209-13P)
17	LVC107	Pine stand with reclaimed peat soil (609-175-5)
18	LVC108	Birch stand with drained organic soil (Mežole, 031-99-9)
19	LVC109	Black alder stand with naturally moist peat soil (505-84-3)
20	LVC110	Pine stand with naturally moist organic soil (508-88-11)
21	LVC111	Birch stand with naturally moist peat soil (Mežole, 012-186-1)
22	LVC112	Clear-cut fir trees are grown with drained organic soil (Mežole, 031-51-11)
23	LVC113	Spruce stand with drained organic soil, control for ash use (Mežole, 012-203-1)
24	LVC115	Birch in drained organic soil on former agricultural land (503-432-8)
25	LVC116	Clear-cut pine trees are grown with drained organic soil (Mežole, 012-193-27)
26	LVC302	Afforestation of grassland with drained organic soil (Rucava, 024-4-1 and 024-3-7)
27	LVC303	Forest paludiculture - afforestation with black alder and birch (Mežole, 031-1-1)
28	LVC306	Agro-forestry – plantation of woody plants with fescue sowing in arable land with improved organic soil (Andrupēni)
29	LVC307	The use of wood ash in a spruce stand with reclaimed peat soil after maintenance felling (Mežole, 012-203-1)
30	LVC308	Selective felling of fir trees with improved organic soil (Mežole, 031-21-21)
31	LVC309	Regeneration with black alder in deciduous trees with naturally moist peat soil, using deep furrow nets (Mežole, 012-218-4)
32	LVC311	Black alder plantation in an area with naturally moist organic soil adjacent to the protective strip of the forest coastal strip (Mežole, 012-218-8)
33	LVC312	Paludiculture – restoration of a spruce stand with naturally moist organic soil using deep furrow nets (Mežole, 031-108-4)
34	LVC313	Strip felling in a pine stand with improved organic soil (Mežole, 12-193-27)
35	LVC310	Planting of fast-growing tree species in the protection zone of drainage systems (Andrupēni)

Table 18. Climate change mitigation measures

Demonstration and reference object number and brief description	ID	Steady state before the event	The situation after the implementation of the measure
LVC301 Transformation of arable land with drained organic soil into grassland	LVC301	LVC101	LVC102

Demonstration and reference object number and brief description	ID	Steady state before the event	The situation after the implementation of the measure
(Andrupēni and Vecauce)			
LVC302 Afforestation of grassland with drained organic soil (Rucava, 024-4-1 and 024-3-7)	LVC302	LVC102	LVC104
LVC303 Forest paludiculture - afforestation with black alder and birch (Mežole, 031-1-1)	LVC303	LVC102	LVC109
LVC304 Use of papilionaceous plants in plant rotation in arable land with drained organic soil (Lazdiņi, Slampe)	LVC304	LVC101	LVC304
LVC305 Controlled drainage in grassland with drained organic soil (Vecauce)	LVC305	LVC101	LVC305
LVC306 Agro-forestry – plantation of woody plants in arable land with drained organic soil (Andrupēni)	LVC306	LVC101	LVC306
LVC307 Use of wood ash in a spruce stand with improved peat soil after maintenance felling (Mežole, 012-203-1)	LVC307	LVC104	LVC307
LVC308 Selective felling of fir trees with improved organic soil (Mežole, 031-21-21)	LVC308	LVC104	LVC308
LVC309 Regeneration with black alder in a forest stand with naturally moist peat soil using deep furrow netting (Mežole, 012-218-4)	LVC309	LVC109	LVC309
LVC310 Planting of fast-growing tree species in the protection zone of drainage systems (Andrupēni)	LVC310	LVC101	LVC310
LVC311 Black alder plantation in an area with naturally moist organic soil adjacent to the forest coastal belt protection belt (Smiltene, 012-218-8)	LVC311	LVC109	LVC309
LVC312 Paludiculture - regeneration of spruce stands with naturally moist organic soil using deep furrow nets (Mežole, 031-108-4)	LVC312	LVC110	LVC312
LVC313 Strip felling in a pine plantation with improved organic soil (Mežole, 012-193-27)	LVC313	LVC107	LVC313

Comparison of scenarios is done separately – including and excluding replacement effect of forest biofuel. Business as usual and mitigation scenario are characterized by net GHG emissions, net emissions excluding biofuel substitution effect, carbon in biomass in herbaceous and forest floor vegetation, total costs, total income and cash flow. Monetary values are calculated for the forest management and afforestation related scenarios. Based on these figures additional costs, reduction of GHG emissions, reduction of GHG emissions excluding biofuel substitution effect, cumulative reduction of GHG emissions and cumulative reduction of GHG emissions excluding biofuel substitution effect are calculated. There is also possibility to calculate discounted costs and income, discounted cash flow, GHG mitigation (except biofuel substitution effect) costs depending from discount rate, as well as mitigation effect and monetary outputs depending from duration of calculation period and starting point.

For projections of GHG emissions and removals several climate change mitigation (CCM) scenarios were applied, covering climate change mitigation measures, as implemented during action C3. CCM measures selected for testing to be implemented in forest land can be divided into three groups: (1) measures related to afforestation and forest restoration, (2) measures that target increasing of tree cover through agroforestry and (3) measures that aim at increase in forest carbon stocks (in soil and biomass) through the modification of forest management practices.

4.1. Afforestation and forest restoration measures

Conventional afforestation considering shorter rotation (Site LVC302)

Afforestation on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm during the growing season. After study site is established normal functioning of the drainage system should be ensured. planned forest type Kp (Latvian classification – platlapju kūdrenis), the dominant tree species – spruce, forest stand formula 10E+B. There are no managing restrictions planned in study site. After GHG measurement activities are completed site should be managed in accordance to the best management practice for spruce plantation forest on organic soil.

Paludiculture – afforestation of grassland with black alder and birch (Site LVC303)

Paludiculture implemented on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm during the growing season. Implemented to demonstrate the reduction of GHG emissions by establishing forest paludiculture (dominant species - black alder and birch) in grassland with nutrient –rich organic soil and increased groundwater level. Some site preparation to maintain water level was performed: cleaning of drainage diches by preparing up to 50 cm deep furrows to ensure (if needed) water runoff from the bordering areas and preparation of up to 50 cm deep furrows also in the site area to ensure runoff of excess surface water. Cleaning of existing overgrowth to prepare the area for afforestation was performed. Planned forest type Db (Latvian classification – dumbrājs), the dominant tree species – black alder, forest stand formula 6Ma4B there are no managing restrictions planned in study site. After completion of GHG measurement activities site should be managed in accordance with the best management practice for mixed deciduous tree stands in wet circumstances.

4.2. Agroforestry measures

Conversion of cropland used for cereal production into grassland considering periodic ploughing (Site LVC301)

Conversion from cropland to grassland is implemented on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm deep during the growing season. Area is managed as cropland. GHG emissions reduction is demonstrated through transformation of cropland to grassland. Projected reduction of GHG emissions is related to the decrease of N_2O and CO_2 emissions from soil. There are no managing restrictions envisaged in the study site. Ploughing should be avoided within at least 5 years period.

Introduction of legumes in conventional farm crop rotation (site LVC304a)

Legumes introduced on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm deep during the growing season. Area is managed as cropland. GHG emissions reduction is demonstrated by introduction of legumes (biomass and nitrogen attraction) to crop rotation. Projected reduction of GHG emissions is related to the decrease of N_2O and CO_2 emissions from soil.

Introduction of legumes in conventional farm crop rotation (site LVC304b, Slampe)

Legumes introduced on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm deep during the growing season. Area is managed as cropland. GHG emissions reduction is demonstrated by introduction of legumes (biomass and nitrogen attraction) to crop rotation. Projected reduction of GHG emissions is related to the decrease of N_2O and CO_2 emissions from soil.

Controlled drainage of grassland considering even groundwater level during the whole vegetation period (site LVC305)

Measure implemented on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm from ground surface during the growing season. The area managed as grassland. GHG emissions reduction is demonstrated from organic soils due to limited fluctuations of groundwater level during and outside the growing season, reduced leaching of nutrients to surface water bodies as drainage water will be stored in the field. It is expected that during the summer season additional water will be available to meet crop demand thus ensuring higher carbon inputs into soil. There are no specific managing restrictions envisaged in the study site.

Agroforestry – fast growing trees and grass (Site LVC306)

Agroforestry is implemented on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm during the growing season. Area is managed as cropland. GHG emissions reduction is demonstrated through transformation of cropland to tree plantation. Projected reduction of GHG emissions is related to the decrease of N_2O and CO_2 emissions from soil as well as to the increase of CO_2 removals in living biomass and other carbon pools. Planned forest type Kp (Latvian classification – dumbrājs), the dominant tree species – poplar, forest stand formula 10Pa; tree cover is not present, planned site index – I. there are no managing restrictions envisaged in the study site. After GHG measurement activities are completed, the site should be managed in accordance to the recommendations of good practice, envisaging up to 20 years rotation period for poplar and up to 5 years for willows.

Fast growing species in riparian buffer zones (site LVC310)

Measure is implemented on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm during the growing season. Area managed as cropland. GHG emissions reduction is demonstrated through transformation of strip areas along drainage diches in cropland to tree plantation areas that avoid nutrient leaching and increase carbon removals in living biomass and other carbon pools. Projected reduction of GHG emissions is related to the decrease of N_2O and CO_2 emissions from soil as well as to the increase of CO_2 removals in living biomass and other carbon pools. There are no managing restrictions envisaged in the study site. After GHG measurement activities are completed, the site should be managed in accordance to the recommendations of good practice, envisaging up to 20 years rotation period for poplar and up to 5 years for willows.

4.3. Carbon stock enhancement via forest management

Riparian buffer zone in forest land planted with black alder (Site LVC311)

Measure implemented on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm during the growing season. Dominant tree species – birch, aspen or black alder. Stand age or basal area of dominant tree species has reached thresholds set for regeneration felling. GHG emissions reduction is demonstrated in deciduous tree stands on organic soils with increased ground water table by enhancing tree growing conditions, using high quality planting material and preparing soil with mounding method including establishing of deep furrows for excess surface water drainage in spring time and after rainfalls. Projected reduction of GHG emissions is related to groundwater level reduction, related to establishment of deep furrows - as a result decreasing CH_4 emissions and increasing CO_2 removals in living biomass because of significantly enhanced tree growing conditions in riparian zone. Existing forest type Db (Latvian classification – dumbrājs), the dominant tree species – spruce, forest stand formula according to State Forest Register 6E872B1A1M80; in accordance to State Forest Register data – average tree height 24 m, diameter – 26 cm, forest stand basal area – 40 m ha^{-1}, growing stock – 475 m^3 ha^{-1}, site index – II. there are no managing restrictions planned in the study site. After GHG measurement activities are completed, site should be managed in accordance to the best management practice for deciduous tree stands in wet circumstances.

Forest regeneration (coniferous trees) without reconstruction of drainage systems (Site LVC312)

Measure implemented on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm during the growing season. Dominant tree species – birch, aspen or black alder. Stand age or basal area of dominant tree species has reached thresholds set for regeneration felling. GHG emissions reduction is demonstrated in coniferous stands on organic soils and increased ground water table by application of forest regeneration with high quality coniferous planting material and by using mounding method (and deep furrows to drain excess surface water during springtime and after heavy rains) for soil preparation. Projected reduction of GHG emissions is related to groundwater level reduction, related to establishment of deep furrows - as a result decreasing CH_4 emissions and increasing CO_2 removals in living biomass because of enhanced forest growing conditions. Forest type Db (Latvian classification – dumbrājs), the dominant tree species – birch, forest stand formula according to State Forest Register 6B2E2M93; in accordance to State Forest Register data

– average tree height 20 m, diameter – 28 cm, forest stand basal area – 21 m ha^{-1}, growing stock – 212 m^3 ha^{-1}, site index – III. There are no managing restrictions planned in the study site. After GHG measurement activities are completed, site should be managed in accordance to the best management practice for spruce stands in wet circumstances.

Strip harvesting in pine stand (Site LVC313

Implemented on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm during the growing season. Dominant tree species – pine, stand age or basal area of dominant tree species has reached thresholds set for regeneration felling. GHG emissions reduction is projected in pine stand by replacing clear felling with strip harvesting. Projected reduction of GHG emissions is related to the increase of groundwater level in an alternative – clear felling scenario. Increase of groundwater level is associated with significant increase of CH_4. In the case of strip harvesting increase of groundwater levels should be smaller thus also increase of GHG emissions is smaller. Forest type Ks (Latvian classification – šaurlapju kūdrenis), the dominant tree species – pine, forest stand formula according to State Forest Register 10P138; in accordance with State Forest Register data – average tree height 22m, diameter – 33 cm, forest stand basal area – 26 m ha^{-1}, growing stock – 350 m^3 ha^{-1}, site index – IV. There are no managing restrictions planned in the study site. After GHG measurement activities are completed, site should be managed in accordance to the best management practice for coniferous tree stands in wet circumstances. Un-felled strips should be felled and planted within the 15-20 year period after strip felling.

Application of wood ash after commercial thinning in spruce stand (Site LVC307)

Measure implemented on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm during the growing season. Dominant tree species – spruce, stand basal area in dimensions to perform thinning by establishing up to 4 m wide technological corridors in every 20 meters (if such are no established before). GHG emissions reduction is demonstrated in spruce stands on organic soils and lowered ground water table by implementation of wood ash after thinning thus enhancing stand growing conditions. Projected reduction of GHG emissions is related to groundwater level reduction, related to increase in growing stock increment and increased water amount used for transpiration processes – thus decreasing CH_4 emissions and increasing CO_2 removals in living biomass. Forest type Kp (Latvian classification – platlapju kūdrenis), the dominant tree species – spruce, forest stand formula according to State Forest Register 7E45 3B42; in accordance to State Forest Register data – average tree height 16 m, diameter – 15 cm, forest stand basal area – 30 m ha^{-1}, growing stock – 240 m^3 ha^{-1}, site index – II. There are no managing restrictions planned in the study site. After GHG measurement activities are completed, site should be managed in accordance to the best management practice for spruce stands in wet circumstances.

Continuous forest cover as a forest regeneration method in spruce stand (Site LVC308)

Implemented on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm during the growing season.

Dominant tree species – spruce, stand age or basal area of dominant tree species has reached thresholds set for regeneration felling. GHG emissions reduction in spruce stand is projected by replacing clear felling with selective felling. Projected reduction of GHG emissions is related to the increase of groundwater level in an alternative – clear felling scenario. Increase of groundwater level is associated with significant increase of CH_4. In the case of selective felling increase of groundwater levels should be smaller thus also increase of GHG emissions is smaller. forest type Kp (Latvian classification – platlapju kūdrenis), the dominant tree species – spruce, forest stand formula according to State Forest Register 8E2B138; in accordance to State Forest Register data – average tree height 26m, diameter – 30cm, forest stand basal area – 29 m ha^{-1}, growing stock – 341 m^3 ha^{-1}, site index – III. there are no managing restrictions planned in the study site. After GHG measurement activities are completed, site should be managed in accordance to the best management practice for coniferous tree stands in wet circumstances.

Semi-natural regeneration of regeneration felling site with grey alder without reconstruction of drainage systems (Site LVC309)

Measure implemented on nutrient – rich organic soil (low bog peat soil according to Latvian classification), peat layer thickness at least 30 cm, groundwater level at least 30 cm during the growing season. Dominant tree species – black alder or birch, stand age or basal area of dominant tree species has reached thresholds set for regeneration felling. Projected reduction of GHG emissions is related to groundwater level stabilizing during forest regeneration phase and better growth conditions and increased CO_2 removals in forest biomass and other carbon stocks. Stabilized groundwater levels (by establishing deep furrows for excess water runoff) will decrease CH_4 emissions, but mounds will ensure better growth conditions for forest regeneration during the first decades after planting. Improved planting material ensure considerably better forest increment and stand resistance to environmental conditions during the whole rotation period. forest type Db (Latvian classification – dumbrājs), the dominant tree species – spruce, forest stand formula according to State Forest Register 9E1B80; in accordance to State Forest Register data – average tree height 21m, diameter – 21cm, forest stand basal area – 31 m ha^{-1}, growing stock – 320 m^3 ha^{-1}, site index – II. There are no managing restrictions planned in the study site. After GHG measurement activities are completed site should be managed in accordance to the best management practice for deciduous tree stands in wet circumstances.

5. Projections of GHG emissions/removals balance in Baltic countries

All Baltic countries, as parties of UNFCCC and it's Kyoto Protocol as well as members of European Union, shall report both to the UNFCCC secretariat and European Commission on greenhouse gas emissions and removals (National GHG Inventories – NIRs) and on climate policies and measures and projections (Policies and Measures Report, biennal reports and national communications). Mandatory rules for GHG inventory (including projections) cover IPCC 2006 Guidelines for National Greenhouse Gas Inventories. Countries are encouraged to use 2013 Supplements to the 2006 IPCC Guidelines and also may voluntarily use 2019 Refinement to 2006 Guidelines. Updated methodology include, among other changes, updated emission factors for estimation of greenhouse gas emissions from organic soils (drained and undrained). In order to improve the reporting and apply higher methodological Tier for national GHG inventories countries are looking for a region or country-specific emission factors for this reporting category to better represent natural and climatic conditions. The importance of the emission factor applied is indisputable as emissions form organic soils are a key reporting category in all Baltic countries.

Baltic countries are reporting GHG emissions from organic soils differently – Latvia has currently implemented several national emission factors from previous research projects, replacing default emission factors provided in the 2013 IPCC Wetlands Supplement. Lithuania is still using default emission factors for drained organic soils provided in 2006 IPCC Guidance due to the 2013 Wetlands Supplement not being mandatory. Estonia is using Swedish emission factors for drained organic forest, cropland, grassland and wetlands (areas for peat extraction) soils, since default IPCC 2006 EFs would likely cause underestimation of emissions (according to the recommendation after IPCC review).

Projections of GHG emissions from wet and drained organic soils were prepared applying national projected land use areas and area changes until 2050 and emission factors developed during previously implemented research projects – LIFE REstore and SNS-120.

Land use and land use change areas were projected taking into account GHG emission reduction and enhancing removal potential policies and measures already applied in the LULUCF sector. Projections of areas prepared taking into account official land use area projections as provided in the most recent Policies and Measures And Projections of Greenhouse Gas Emissions report of the countries (submitted to UNFCCC by 2021).

Projections of GHG emissions were prepared with current emission factors applied and new national/regional emission factors developed, the effect of the change in methodology was also estimated.

5.1. Latvia

All evaluated measures are compared by the effect reached during 50 years period. The default values applied in the model are used in the report. They are based on the GHG fluxes acquired in study sites in Latvia by comparison of two reference scenarios according to Table 17 and 18.

Transformation of arable lands with organic soil into grasslands is one of the most common measures in real life conditions. In spite the results acquired during the study demonstrates either increase or reduction of the emissions due to implementation of this measure. In optimistic scenario net emission reduction in the 50 years period will reach 133 tons CO_2 eq ha^{-1}, 2.66 tons CO_2 eq ha^{-1} yr^{-1} (Table 19). Bioenergy production doesn't have effect in this measure. It is assumed that grassland is used for fodder production without additional input of organic fertilizers.

Table 19. LVC301 Transformation of arable land with drained organic soil into grassland

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	133
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	133

Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	-

Afforestation of grassland with organic soil is one of the most efficient measures with relatively smallest risk of implementation. It is the next step for reduction of GHG emissions after conversion to grassland of arable land with organic soil; respectively, in case of afforestation of cropland with organic soil the net effect included the values listed in Table 19. In optimistic scenario net emission reduction in the 50 years period will reach 406 tons CO_2 eq ha^{-1}, 8.13 tons CO_2 eq ha^{-1} yr^{-1} (Table 20). Bioenergy production will contribute to additional substitution effect – 92 tons CO_2 eq ha^{-1} yr^{-1}. The positive effect can be increased further by periodic application of wood ash and mineral fertilizers. In the calculation is is assumed that the area is afforested with spruce and drainage system is well maintained to avoid periodic flooding of the afforested area, selection of other species may result in different mitigation effect.

Table 20. LVC302 Afforestation of grassland with drained organic soil

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	498
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	406
Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	92

Afforestation of grassland with organic soil with following rewetting is less efficient, but still feasible mitigation measure. It is important that the first step is afforestation and rewetting follows to it to avoid risk of disturbances, e.g. due to periodic flooding before forest is able to regulate groundwater level by evapotranspiration. In case of opposite order the risk not to reach awaited mitigation effect significantly increases due to natural disturbances. In optimistic scenario (forest stand survives) net emission reduction in the 50 years period will reach 317 tons CO_2 eq ha^{-1}, 6.35 tons CO_2 eq ha^{-1} yr^{-1} (Table). Bioenergy production will contribute to additional substitution effect – 14 tons CO_2 eq ha^{-1} yr^{-1}. The positive effect can be increased further by periodic application of wood ash and mineral fertilizers. In the calculation is is assumed that the area is afforested with birch or black alder.

Table 21. LVC303 Forest paludiculture – afforestation with black alder or birch

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	331
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	317
Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	14

We did not observed reduction of GHG emissions from soil during growing of legumes in cropland. Actually, due to smaller carbon input with plant residues this scenario results in slightly increased GHG emissions; however, this increase is negligible – 2 tons CO_2 eq ha^{-1} during 50 years period (Table 22). Further studies are necessary to evaluate cumulative effect in agriculture sector and to improve biomass expansion factors applied to calculate carbon input using different plant species rotations.

Table 22. LVC304 Use of papilionaceous plants in plant rotation in arable land with drained organic soil

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	-2
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	-2
Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	-

Similarly, we did not observed reduction of GHG emissions from soil after implementation of controlled drainage in grassland. Due to slight increase of CO_2 and CH_4 emissions in the area with regulated groundwater level the net emissions from the area increased; however, this increase is negligible – 27 tons CO_2 eq ha^{-1} during 50 years period (Table 23). Further studies are necessary to evaluate long term effect of the groundwater level regulation. The short term increase may be associated with improved water regime in summer resulting in an increase of CO_2 emissions. It is also important that we used in the calculation average carbon input with plant residues, while better water regime during summer may be also associated with bigger biomass production rate. Further studies are necessary to evaluate these factors.

Table 23. LVC305 Controlled drainage in grassland with drained organic soil

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	-27
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	-27
Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	-

Growing of fast growing trees in arable land with organic soil is the most efficient measure with the biggest implementation potential; however, it is also associated with significant risks of natural disturbances. In our trials the plantation suffered from draught and animal damages, pointing out that fencing is mandatory action to succeed with this measure. It seems that drought is important risk in organic soils, and it can be avoided by proper soil scarification, use appropriate (thick) planting material and deep planting. In optimistic scenario (plantation survives and is not significantly damaged by draught or animals) net emission reduction in the 50 years period will reach 1067 tons CO_2 eq ha^{-1}, 21.34 tons CO_2 eq ha^{-1} yr^{-1} (Table 24). Bioenergy production will contribute to additional substitution effect – 509 tons CO_2 eq ha^{-1} yr^{-1}. It is assumed that the plantation is primarily used for timber and pulp production. In case of bioenergy targeted plantation the most of the effect will appear as a substitution effect in energy sector. The positive effect can be increased further by periodic application of wood ash and mineral fertilizers. In the calculation is is assumed that the area is planted with hybrid poplar and drainage system is well maintained to avoid periodic flooding of the plantation. Selection of other species, e.g. hybrid aspen or alder, may result in different mitigation effect.

Table 24. LVC306 Agro-forestry – plantation of woody plants in arable land with drained organic soil

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	1576

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	1067
Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	509

Application of wood ash in peat soils is forest lands is well known for being efficient measure rapidly increasing CO_2 in living biomass. In optimistic scenario (the stands fulfils criteria for application of wood ash – it is thinned and do not suffers from other disturbances) net emission reduction in the 50 years period will reach 124 tons CO_2 eq ha^{-1}, 2.47 tons CO_2 eq ha^{-1} yr^{-1} (Table 25). Bioenergy production contributes negatively in this period – -23 tons CO_2 eq ha^{-1} yr^{-1}. It is associated with different output of small dimension logs in the calculation period due to application of wood ash. In long term (200 years period) additional effect of forest biofuel is about 10% o the total mitigation effect. In the calculation is is assumed that the wood ash is applied in spruce stands and drainage system is well maintained to avoid periodic flooding. Similar effect can be achieved in pine stands. Further studies are necessary to evaluate the effect in deciduous tree stands.

Table 25. LVC307 Use of wood ash in a spruce stand with improved peat soil after maintenance felling

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	101
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	124
Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	-23

Selective felling in spruce stands is aimed at reduction of GHG emissions during the forest regeneration stage, when evapotranspiration rate decreases and groundwater level raises resulting in significant increase of CH_4 emissions, as well as CO_2 emissions due to decomposition of harvesting residues. In Baltic state selective felling in forests with organic soils is associated with additional risks due to disturbances after harvesting, e.g. wind-throws, snow damages, distribution of pests, thus minor GHG mitigation effect may be associated with bigger emissions due to extended regeneration period if salvage logging is following to selective felling. In optimistic scenario (the stand survives after selective felling, and no significant disturbances takes place in following years) net emission reduction in the 50 years period will reach 30 tons CO_2 eq ha^{-1}, 0.59 tons CO_2 eq ha^{-1} yr^{-1} (Table 26). Bioenergy production contributes negatively in this period – -23 tons CO_2 eq ha^{-1} yr^{-1}. It is associated with different management practices. In long term (200 years period) additional effect of forest biofuel is about 10% o the total mitigation effect. This kind of selective fellings can be implemented only in spruce stands, which is the only shade tolerant native tree species here. For other species selective felling by making openings can be applied. It is assumed in the calculation that drainage systems are well maintained.

Table 26. LVC308 Selective felling of spruce stand with drained organic soil

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	7
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	30

Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	-23

Forests with naturally wet organic soils are usually regenerated naturally, by seeds and sprouts, thus, the regeneration period is significantly longer in comparison to artificial regeneration, resulting in high CH_4 emission rate, as well as significantly smaller removals of CO_2 in living biomass and other carbon pools. Artificial regeneration ensures additional breeding effect as CO_2 removal. Unfortunately GHG measurement data are not available for longer time frame and in this study it assumed that the net GHG emissions from soil equals to the emissions in drained sites because of significantly increased evapotranspiration rate. In spite of increase of CO_2 removals in living biomass by about 100 tons CO_2 during the 70 years rotation period, the conservative approach applied to estimate soil emissions leads to negative mitigation effect; during 50 years period the net emissions increases by 41 tons CO_2 eq ha^{-1}, 0.82 tons CO_2 eq ha^{-1} yr^{-1} (Table 27). Bioenergy production contributes positively in this period by reduction GHG emissions by 29 tons CO_2 eq ha^{-1} yr^{-1}. In optimistic scenario, assuming that the awaited additional increment is reached and GHG pattern differences observed in the demo sites will continue or will return to the level of the fluxes typical for wet organic soils, the net emission reduction in 50 years period would reach about 80 tons CO_2 eq. ha^{-1}. Further studies are necessary to evaluate effect of this measure.

Table 27. LVC309 Regeneration with black alder in a forest stand with naturally moist peat soil using deep furrow netting

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	-12
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	-41
Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	28

Growing of fast growing trees as a shelter belts in arable land or grassland with organic soil is one of the most efficient measures with significant implementation potential; however, it is also associated with significant risks of natural disturbances, considering that fast growing tree species are planted in the shelter belts. In our trials the plantation suffered mechanical and animal damages, pointing out that fencing or other plant protection measures are mandatory to succeed with this measure. As mentioned before, drought is significant risk in organic soils, and it can be avoided by proper soil scarification, use appropriate (thick) planting material and deep planting. In optimistic scenario (shelter belt survives and is not significantly damaged by draught or animals) net emission reduction in the 50 years period will reach 1067 tons CO_2 eq ha^{-1}, 21.34 tons CO_2 eq ha^{-1} yr^{-1} (Table 28). Bioenergy production will contribute to additional substitution effect – 509 tons CO_2 eq ha^{-1} yr^{-1}. It is assumed that the shelter belt is primarily used for timber and pulp production. In case of bioenergy targeted plantation the most of the effect will appear as a substitution effect in energy sector. In the calculation is is assumed that the area is planted with hybrid poplar. Selection of other species, e.g. hybrid aspen or alder, may result in different mitigation effect.

Table 28. LVC310 Planting of fast-growing tree species in the protection zone of drainage systems

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	1576
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	1067
Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	509

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

Table 29. LVC311 Black alder plantation in an area with naturally moist organic soil adjacent to the forest coastal belt protection belt

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	-12
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	-41
Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	29

Another option of artificial regeneration of naturally wet organic soils in forest lands in planting of spruce or pine on mounds, ensuring that trees have favourable growth conditions during the first year of development. The artificial regeneration ensures additional breeding effect as CO_2 removal in living biomass. In this study it assumed that the net GHG emissions from soil in case of artificial regeneration equals to the emissions in drained sites because of significantly increased evapotranspiration rate. In contrast to deciduous forests with naturally wet soils this measure have positive effect even using conservative approach for calculation of soil GHG fluxes, in 50 years period the net emissions reduces by 148 tons CO_2 eq ha^{-1}, 2.95 tons CO_2 eq ha^{-1} yr^{-1} (Table 30). Bioenergy production contribution is negligible in 50 years period, but significantly increase after 80 years. In spite the measure results in significant GHG mitigation and has considerable implementation potential, it is also associated with different risks of natural disturbances; therefore during the regeneration stage it is important to establish remedial drainage system to ensure that trees are not suffering from exceeding amount of water during the early development stage.

Table 30. LVC312 Paludiculture – regeneration of spruce stands with naturally moist organic soil using deep furrow nets

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	144
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	148
Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	-4

Strip or spot felling in pine stands is aimed at reduction of GHG emissions during the forest regeneration stage, when evapotranspiration rate decreases and groundwater level raises resulting in significant increase of CH_4 emissions, as well as CO_2 emissions due to decomposition of harvesting residues. Just like selective felling in in spruce stands strip felling in pine or birch felling in forests with organic soils is associated with additional risks due to disturbances after harvesting, e.g. wind-throws and distribution of pests, thus minor GHG mitigation effect may be associated with bigger emissions due to extended regeneration period if salvage logging is following to selective felling. In pine stands additional potential drawback of openings is insufficient amount of sunlight at sides of openings, resulting in decreased growth rate. In optimistic scenario (the stand survives after strip felling, and no significant disturbances takes place in following years) net emission reduction in the 50 years period will reach 6 tons CO_2 eq ha^{-1}, 0.12 tons CO_2 eq ha^{-1} yr^{-1} (Table 31). Bioenergy production doesn't effect the net GHG emissions during the first 50 years after the forest regeneration, but have significant role in long term. This measure requires additional investigation, particularly, to evaluate growth rate and potential risks.

Table 31. LVC313 Strip felling in a pine plantation with improved organic soil

Parameter	Measurement unit	Value
Cumulative GHG mitigation effect	tons CO_2 eq ha^{-1}	6
Cumulative GHG mitigation effect excluding biofuel substitution effect	tons CO_2 eq ha^{-1}	6
Biofuel substitution effect in the cumulative GHG emission reduction	tons CO_2 eq ha^{-1}	0

Suggestions/recommendations for policy makers and further development of projections

The study results proves LVC301 Transformation of arable land with drained organic soil into grassland can significantly reduce GHG emissions and it is less costly measure; however, it's effect is nearly six times smaller than the effect of afforestation (LVC302). Afforestation with grasslands with following rewetting (LVC303) is another measure with significant mitigation and implementation potential; however, it is also associated with higher risk of natural disturbances. Remedial or temporal ditching is very important during the regeneration stage to reduce this risk. Use of wood ash in a spruce stand (LVC307) with drained organic soil after thinning is another efficient and "fast acting" measure ensuring significant amount of additional CO_2 removals in living biomass in short period of time. Agro-forestry – plantation of woody plants in arable land with drained organic soil (LVC306) in theory is the most efficient measure; however, it is also the most expensive and associated with bigger risk of natural disturbances; therefore, requires protection and more attention during the regeneration stage than the afforestation related measures. Planting of fast-growing tree species in shelter belts (LVC310) of drainage systems have similar effect; however, it is even more expensive and complicated in the implementation stage. Above mentioned measures can be recommended for the National climate and energy actin plans and other support schemes to implement short term and long term climate neutrality targets.

We did not observed in our study positive effect of the use of legumes LVC304 in plant rotation in arable land with drained organic soil and controlled drainage in grassland (LVC305) with drained organic soil. Similarly, we did not observed significant positive effect of strip felling in a pine stands (LVC313). These measures requires further investigations before recommendation for implementation in the national climate and energy programs.

Selective felling in spruce stands (LVC308) demonstrated positive effect on GHG emissions from soil; however, this effect can be neglected by the fact that logging area should be increased at least three times to acquire the same amount of wood, and cumulative emissions from such, extended area may be even bigger than from smaller clear-felling site. Additionally, selective felling is associated with the increased risk of natural disturbances, it makes impossible artificial regeneration, thus loosing breeding effect (15-20% of additional removals in living biomass) and it can contribute to negative selection by leaving weaker and removing stronger trees during felling. Strip or spot harvesting in spruce stands should be evaluated further to evaluate if the effect of the mitigation of emissions from soil is retained in the smaller, e.g. 0.5 ha, openings.

Artificial regeneration with black alder (LVC309) or spruce (LVC312) in forest stands by planting trees on mounds and establishing network of furrows to remove exceeding water from topsoil layer seems to be promising solutions, in spite they are associated with bigger risk of natural disturbances. Proper management of risks is the key element for success during implementation of these measures. Further observations are necessary to evaluate the effect on soil GHG fluxes after regeneration. Additional efforts should be paid to elaborate spatial tool for selection of forest stands suitable for implementation of this measure and development of remedial drainage system and network of furrows.

Planting of black alder shelter belts in alluvial zones in areas with organic soil (LVC311) seems to be efficient forestry measure; however, selection of suitable areas may be more complicated than for other measures, particularly, because of management restrictions having potential negative effect on long term carbon storage in HWP and substitution effect. This measure also requires further investigation to evaluate effect of the soil GHG fluxes. However, this measure can be implemented as a part of artificial regeneration of forests with wet organic soils by planting black alder or birch in depressions, where probability of survival of coniferous trees is significantly smaller; thus this measure would also contribute to increase of biodiversity.

5.2. Lithuania

Projections of GHG emissions and removals applying different climate change mitigation measures for Lithuania were prepared with national forest stand growth curves (adjusted Latvian growth curves included in the model), prepared from the data of National Forest Inventory of 2018-2022. All evaluated measures are compared by the effect reached during 50 years period. Applicable emission factors and formulas applied are listed in the report above. The emission factors are based on the GHG fluxes acquired in study sites in Latvia by comparison of two reference scenarios according to Table and **Error! Reference source not found.**. 13 different climate change mitigation measures are evaluated as an example here in the report, however, some more potential climate change mitigation scenarios with different business-as-usual and suggested mitigation measure applied could be prepared with the data included in the model. The comparison of the GHG reduction results in 50 years of implementation of measures listed is presented in Figure 3.

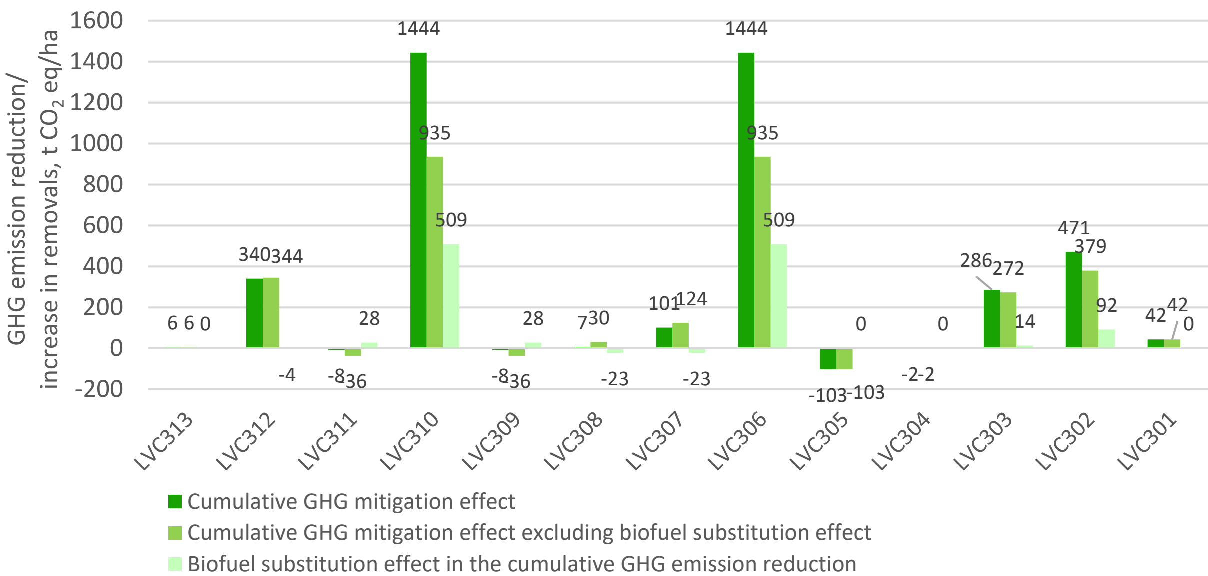

Figure 3. Comparison of the effect of different climate change mitigation measures, tonnes CO_2 eq ha^{-1}

As it can be observed from the results (Fig. 3), the most significant impact for GHG mitigation (increase of GHG removals) is projected with the measures including afforestation with fast growing tree species – fast growing tree species in riparian zones (LVC310) and agroforestry (combination of fast growing trees and grass) (LVC306). These measures, due to the short rotation period and large volumes of wood available, ensure the most significant biofule substitution effect, which may consist more than half of the cumulative GHG mitigation effect of the measure. Second to the largest GHG mitigation measure is conventional afforestation, considering shorter rotation (LVC302), which may generate up to 379 tonnes CO_2 eq. ha^{-1} additional GHG removals, if implemented instead of grassland in 50 years. Unfortunately, some of the measures may even add additional GHG emissions in the long term – controlled drainage in grassland (LVC305), use of papilionaceaus plants in plant rotation in arable land in with drained organic soils (LVC304).

Implementation of these additional measures in soil may lead up to 100 tonnes CO_2 eq. ha^{-1} in 50 years. Conversion from cropland to grassland (LVC301), despite having quite significant impact for GHG removal increase in the past in Lithuania (Ministry of Environment, 2023), is projected to have a rather small (Fig. 3), but stable GHG mitigation impact (42 tonnes CO_2 eq. ha^{-1} in 50 years). Measures covering the maintenance of wet conditions of soil – paludiculture (afforestation of grassland with black alder and birch) (LVC303) and forest regeneration (coniferous trees) without reconstruction of drainage systems (LVC312) – would also ensure additional (up to 340 t CO_2 eq. ha^{-1}) GHG reduction compared to business-as-usual scenario (grassland, pine stand on moist soil). Application of wood ash after the commercial thinning in spruce stand (LVC307) would increase growing stand volume and thus lead to additional GHG removals, compared to the business-as-usual scenario (spruce stand without any fertilization). While continuous cover forestry, however, cannot ensure large amounts of additional GHG removals and also cannot contribute to the biomass substitution effect, as projected according to the findings of the project results.

Fluctutations of annual GHG removals or emissions in each measure applied are provided in the figures below.

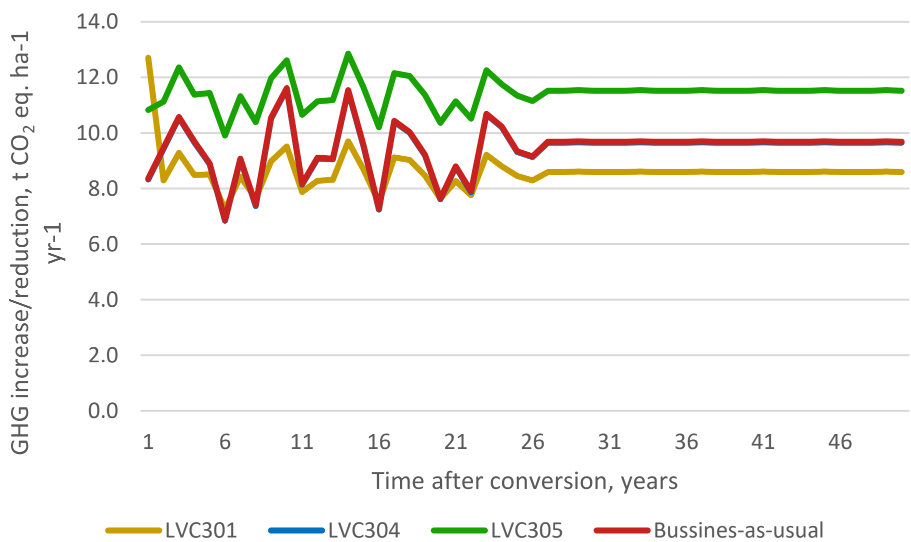

Figure 4. Annual fluctuations of GHG removals and emissions in different climate change mitigation measures: conversion of cropland used for cereal production into grassland considering periodic ploughing (LVC301), introduction of legumes in conventional farm crop rotation (LVC304), controlled drainage of grassland considering even groundwater level during the whole vegetation period (LVC305), tonnes CO_2 eq ha^{-1} yr^{-1}

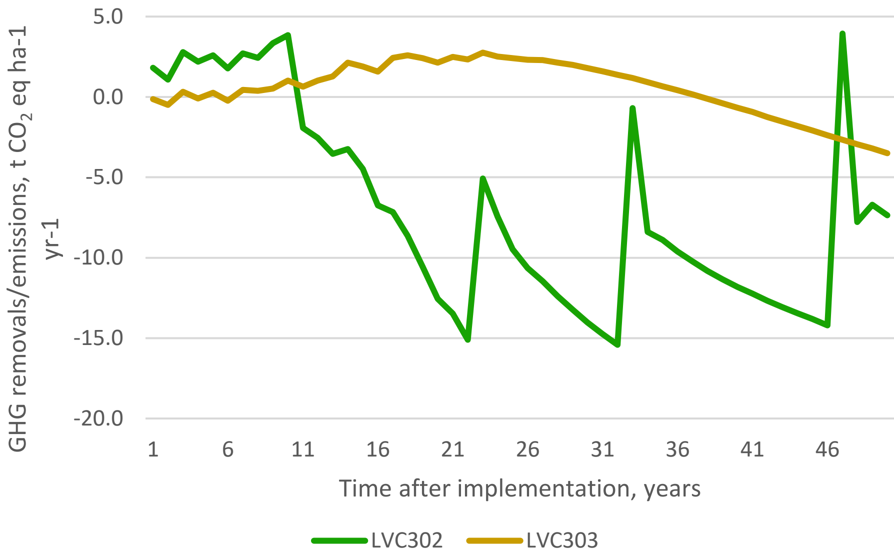

Figure 5. Annual fluctuations of GHG removals and emissions in different climate change mitigation measures: conventional afforestation considering shorter rotation (LVC302), paludiculture – afforestation of grassland with black alder and birch (LVC303), tonnes CO_2 eq ha^{-1} yr^{-1}

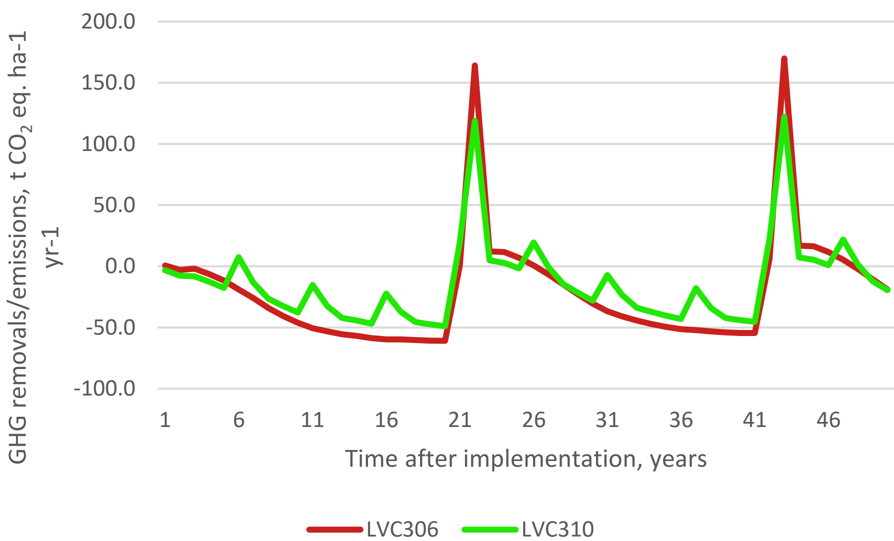

Figure 6. Annual fluctuations of GHG removals and emissions in different climate change mitigation measures: agroforestry – fast growing trees and grass (LVC306), fast growing species in riparian buffer zones (LVC310), tonnes CO_2 eq ha^{-1} yr^{-1}

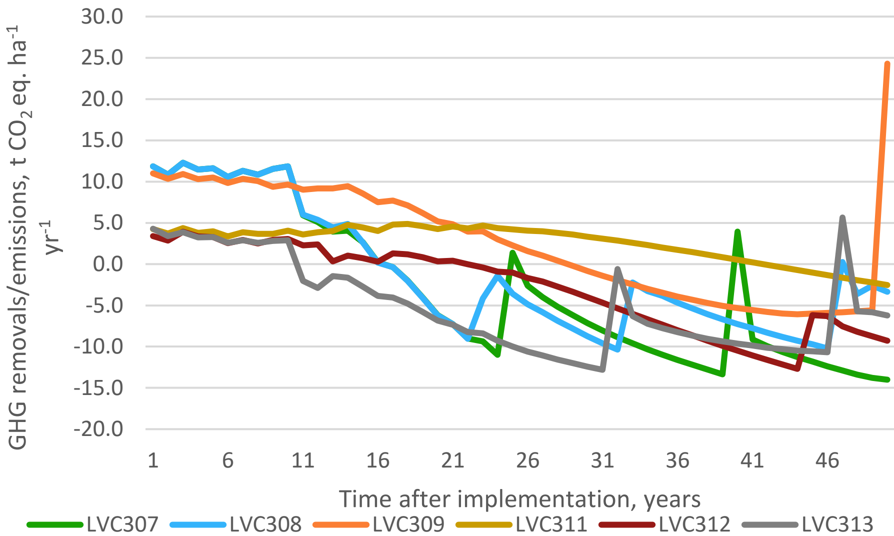

Figure 7. Annual fluctuations of GHG removals and emissions in different climate change mitigation measures: application of wood ash after commercial thinning in spruce stand (LVC307), continuous forest cover as a forest regeneration method in spruce stand (LVC308), semi-natural regeneration of regeneration felling site with grey alder without reconstruction of drainage systems (LVC309), riparian buffer zone in forest land planted with black alder (LVC311), forest regeneration (coniferous trees) without reconstruction of drainage systems (LVC312), strip harvesting in pine stand (LVC313), tonnes CO_2 eq ha^{-1} yr^{-1}

Suggestions/recommendations for policy makers and further development of projections

The study results provide several different potential climate change mitigation measures to reduce GHG emissions and increase GHG removals in LULUCF sector or reduce GHG emissions in other sectors via biomass substitution effect. The most significant addition to GHG removals compared to business-as-usual scenario is ensured due to the introduction of fast growing tree species (scenarios LVC306 and LVC310). In addition to this, conventional afforestation (with shorter rotation) would also result in significant additional GHG removals, however, with much smaller contribution to biomass substitution effect.

Suggested climate change mitigation measures could be additionally analysed taking into consideration the adaptation to climate change of different tree species and their resilience to natural disturbances.

However, in order to reach climate change mitigation aims and maintain biodiversity, the combination of different climate change mitigation measures would serve best both needs, paludiculture and riparian fast growth tree species introduction could not only increase GHG removals, but additionally help to maintain specific habitats for different wildlife species.

Financial costs of the implementation of different measures has been included in the model, however, not analysed for Lithuanian case. In order to better represent national conditions, costs of the implementation and added value should be analysed and updated after additional research of national values available from private organizations or state enterprises.

Climate change has been included as an impact in this study for the projections of GHG emissions from organic soils, however, climate change impact could be considered for the biomass carbon stock changes projection as well. This can be simply introduced to the model via the growth curves of different tree species.

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