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

REPORT

ON IMPLEMENTATION OF THE PROJECT

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

WORK PACKAGE

MONITORING OF THE IMPLEMENTATION OF PROJECT ACTIVITIES

(D.1)

ACTIONS

Deliverable title	**Initial monitoring report**
Deliverable No	D.1.1
Agreement No.	LIFE18 CCM/LV/001158
Report No.	2021-D1|1-1
Type of report	Draft
Organizations	Latvian State Forest Research Institute "Silava"

2021

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

Report title	**Initial monitoring report (D.1.1)**
Work package	Monitoring of the implementation of project activities (D.1)
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Report No.	2021-D1|1-1
Type of report	Draft
Place	Salaspils
Organization	Latvian State Forest Research Institute "Silava"
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Date	2021
Number of pages	25

"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."

2021

Contents

Abbreviations

AFOLU – Agriculture, Forestry and Other Land Use
C – Carbon
Ca – Calcium
CCM – Climate change mitigation measures
CO2 – Carbon dioxide
CH4 – Methane
DNA – Deoxyribonucleic acid
EF – Emission Factor
GHG – Greenhouse Gas or Greenhouse Gases
GLOSOLAN – Global Soil Laboratory Network
IPCC – Intergovernmental Panel on Climate Change
IPCC Guidelines 2006 – 2006 IPCC Guidelines for National Greenhouse Gas Inventories
IPCC KP Supplement – 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol
IPCC Wetlands Supplement – 2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands
IR – Infrared
IRS – Infrared spectroscopy
ITS – internal transcribed spacer
IRGA – infra-red gas analyser
K – Potassium
LSFRI Silava – Latvian State Forest Research institute "Silava"
Luke – Natural Resources Institute Finland "Luke"
LULUCF – Land Use, Land Use Change and Forestry
MEPRD – Ministry of Environmental Protection and Regional Development
Mg – Magnesium
N – Nitrogen
N2O – Nitrous oxide
NO3 – Nitrate
OTU – Operational taxonomic unit
P – Phosphorus
PCR – Polymerase chain reaction
pH – Potential of hydrogen
rRNA - Ribosomal Ribonucleic Acid
UT – University of Tartu
WOM – Without measures
WAM – With additional measures

Introduction

The aim of monitoring the implementation of activities is to evaluate the impact of the implemented measures on greenhouse gas (GHG) emissions in the 16 demonstration sites and 35 reference sites established under action C3 and to compare the identified impacts against the target indicators set out in the monitoring guidelines. In total 51 sites are measured.

The monitoring of the implementation of activities will be developed through three report: initial, mid-term, and final.

The present, initial monitoring report will focus on the description of the different field measurements that will be used within the project to quantify greenhouse gas emissions from nutrient-rich organic soils.

One of the main tasks of the LIFE OrgBalt is in fact the improvement of methodologies for the calculation (Action C1) and projections (Actions C2 and C5) of GHG emissions from drained nutrient-rich organic soils (grassland, cropland, forest land and managed wetlands), thus contributing to the development of National GHG inventory systems and to the implementation of national and global CCM targets. The main indicators of the success of Actions C1, C2 and C5 will be that key sources of GHG emissions and CO_2 removals on organic soils are reported according to tier 3 methodology as requested by the Intergovernmental Panel on Climate Change (IPCC) guidelines, as well as the impact of the climate change mitigation (CCM) measures implemented in managed cropland, grassland and forest land on organic soil.

The reduction of GHG emissions in demo sites will be monitored using GHG measurement methodologies applied in Action C1, including supplementary data on biomass production, weather conditions, soil and water properties. The long-term impact will be modelled using the scenario analysis tool elaborated within the scope of Action C2 and C5. Monitoring data will be used to update the scenario analysis tool for short-term actions like changes in crop rotation, application of wood ash. However, continuation of the measurements after the completion of the Project is of special importance to elaborate accurate impact assessment curves of climate change mitigation (CCM) measures.

The gas measurements in all sampling sites (reference sites established within the scope of C1 and demo sites established within the scope of C3) will be used to improve GHG emission factors (EFs) elaborated in Action C1 and will be utilised in the final revision of the catalogue of CCM measures calculation and projections for WOM (Without measures) and WAM (With additional measures) projections, including recommendation for application of CCM measures for management of organic soils depending on land use, soil properties and climate projections.

Furthermore, considering high research value of the established demo sites, they will be used for monitoring GHG emissions from lands under transition period within the scope of the National CCM related research projects, as well as in training and education activities. Scientific outputs of the Project will be monitored by success of implementation of the proposed methodologies and publishing of Project results.

The benefits, results and effectiveness of the LIFE OrgBalt Project actions are measurable and should be evaluated and documented under the monitoring actions, to be compared with initial data, and to check if they are online with the project objectives and expected results. Specific indicators (measurements of CO_2, CH_4 and N_2O fluxes or emissions, Tier 3 level methodology for emission from relevant sources calculation under National GHG reporting, content of national reports related to international environment policy agreements) to detect the impact of the project activities at local (demonstration site level) and national level, are selected and regular monitoring is foreseen.

The tasks of the Action D.1 “Monitoring of the implementation of project activities” are:

- Task 1: Monitoring of GHG emissions

  Monitoring of GHG emissions in the demonstration and reference sites is one of the key activities in the Project aimed at the verification of the impact of the implemented measures. Within the scope of this action GHG emissions from the sites will be monitored for 24 months following the methodology adopted in Action C1. Where necessary, GHG measurements will be implemented in alternative management regimes representing demo plots and control plots (the latter characterising “business as usual” conditions). In addition, greenhouse gases, water, soil and biomass sampling and analyses will be implemented by Internal resources. The Action has a bidirectional connection with Actions C1 and C2. Results of C1 and C2 (emission factors (EFs), assessment of the climate change effects) will be used to elaborate long-term impact projections, and monitoring results obtained within Action D1, will be used to validate the data obtained in reference sites. The full list of demonstration sites is comprised in Table 1. The main output of this task is measurement data, which will be used in Actions C1 and C2 to elaborate EFs and to improve the quality of the equations used in the projections of GHG emission by the implementation of the short-term effect into the calculations.

- Task 2: Validation of the CCM measures and reporting of monitoring results

  This task aims to elaborate GHG emission reduction estimates in the demonstration sites, monitor the project implementation and elaborate reporting documents. Short-term effect of the applied measures will be evaluated through the Monitoring report (Task D.1.1); long-term effect of the measures will be projected using results of Action C1 and C2 implemented in the scenario analysis model, which will be elaborated within the scope of Action C5.

The methodologies which will be applied to evaluate the project results are described in further chapters. Due to the rapid developments in this field the methodologies may be updated according to up-to-date best practices. The impact of the project climate change mitigation targeted activities implemented within demonstration sites will be measurable through the collection and analyses of the values of the reduction of the GHG emissions in the demonstration sites.

Monitoring of impact of activities

Field measurements

Organic soils contribute to the atmospheric greenhouse gas (GHG) concentrations, as they can both remove and emit GHG emissions, and have globally extensive carbon (C) and nitrogen (N) stores. Currently, both the IPCC (2006) agriculture, forestry and other land use (AFOLU) guidelines and the IPCC (2014) Wetlands Supplement may be used for reporting the annual GHG emissions and removals for soils under anthropogenic land uses. Area-based emission factors (EFs), describing the net annual soil GHG emissions/removals, have been developed to reflect the impacts of ecosystem type, land management, and environmental conditions. Countries may opt for different methodological levels in their GHG reporting, so-called Tiers 1 to 3, where Tier 1 is the simplest approach with default EFs of the IPCC. The accuracy of EFs can be improved as more peer-reviewed data become available and quantify a wider set of specific management options and ecological conditions for a given country or region.

Quantifying the soil GHG balance, especially for carbon dioxide (CO_2), in forests and other ecosystems on organic soils are technically challenging. Monitoring needs to take into account that:

- C-sequestration into plant biomass takes place in a potentially voluminous and diverse vegetation community with uneven spatial distribution,
- C transfer from biomass into dead organic matter takes place both in aboveground and belowground part,
- physical and biochemical characteristics in organic soils change over time,
- CO2 release through heterotrophic processes takes place both in recently deposited litter and in a soil composed of previously accumulated dead organic matter,
- CO2 formed in the heterotrophic processes in the soil must be separated from similarly large CO_2 emissions formed in autotrophic root respiration in flux measurements,
- rates of biological processes change over the year and differ between years depending on weather conditions, stand development and management.

In this document, "soil CO_2 balance" is specified to include C transfer fluxes to the soil as above- and belowground litter, and losses by decomposition of litter and soil organic matter (Figure 1).

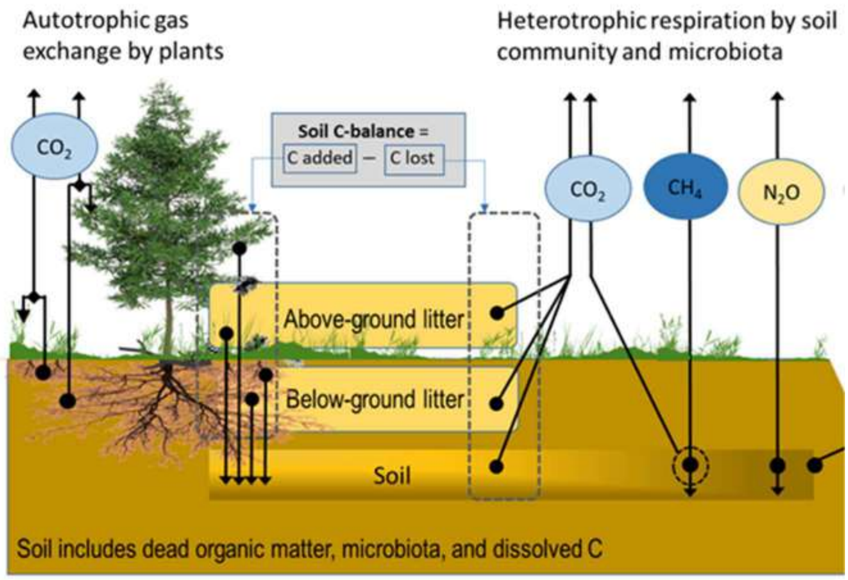


Figure 1. CO_2, CH_4, and N_2O fluxes and mass transfer components (arrows indicate flux/transfer direction) contributing to soil C-stock changes in a forest ecosystem on drained organic soil (as in IPCC, 2014), modified from Jauhiainen et al. (2019).

Soil CO_2 balance formed by using chambers includes typically CO_2 exchange monitoring at soil surface without the presence of ground vegetation and roots, and optionally including or removed aboveground litter from the soil surface. Trenching (explained in subsequent paragraphs) prevents live root presence and regular sprout cutting prevents vegetation growth on the soil surface. Annual soil CO_2 balance is formed by using (1) summarized CO_2 flux data over the year in monitoring and (2) data on mass-based C stock changes, such as C inputs and decomposition as litter aboveground and belowground. Removal/inclusion of above ground litter in CO_2 flux monitoring needs to be considered in soil CO_2 balance equation, i.e., if the litter is removed from the measurement plots, the rates of both the input and decomposition of above ground litter need to be estimated.

For forming the EFs for methane (CH_4) and nitrous oxide (N_2O) there is no guidance on how living vegetation presence or litter dynamics should be taken into account in flux measurements, except that vegetation presence can be reported for CH_4 monitoring locations (IPCC, 2014). Wetland plants that have roots with aerenchymatous tissue are known to pipe out CH_4 from waterlogged peat layers (Askaer et al., 2011; Kokkonen et al., 2019) or attenuate the emissions in drained sites (Strack et al., 2006). Furthermore, belowground biomass disturbance, e.g., rhizosphere and mycorrhizal mycelia removal by trenching, has been shown to result in increased N_2O flux in drained organic forest soils (Ernfors et al., 2011). It seems clear, however, that in studies of CH_4 and N_2O fluxes, vegetation should be kept intact if possible. Annual soil CH_4 and N_2O balance are based on summarized fluxes over the year in monitoring.

The LIFE OrgBalt project aims to implement a wide range of innovative organic soil management measures to demonstrate how these areas can be managed sustainably, taking into account economic, social and climate aspects. 16 project demonstration sites have been established in Latvia and Finland. LIFE OrgBalt studies greenhouse gas emissions from managed organic soils – In total 51 sites will be measured – they include all project demonstration sites and reference sites. Table 1. shows the list of all implemented demonstration sites with a short description of the main benefits of the applied climate change mitigation measures.

Table 1. LIFE OrgBalt demosites

#	Country	Code	CCM measure	CCM benefits
1	Latvia	LVC303	Paludiculture - afforestation of grassland with black alder and birch	Potential benefits of establishment of forest paludiculture in rewetted grassland: ✓ Reduced GHG emissions from soil due to improvement of water regime by mounding and establishment of network of shallow furrows to drain exceeding surface water ✓ Reduction of risks associated with natural disturbances in forests with wet organic soils ✓ Accumulation of CO_2 in living and dead biomass, soil and litter and replacement effect of forest biofuel and harvested wood products
2	Latvia	LVC302	Conventional afforestation considering shorter rotation	Potential benefits of afforestation: ✓ Reduced GHG emissions from soil ✓ Accumulation of CO_2 in living and dead biomass, soil and litter and replacement effect of forest biofuel and harvested wood products ✓ Shorter rotation and more intensified management ensure higher yield and replacement effect, as well as reduces carbon losses due to root rot and other disturbances
3	Latvia	LVC308	Continuous forest cover as a forest regeneration method in spruce stands	Potential benefits of continuous forest cover: ✓ Reduced CH_4 and N_2O emissions from soil due to avoiding of increase of the groundwater level after harvesting
4	Latvia	LVC307	Application of wood ash after commercial thinning in spruce stands	Potential benefits of wood ash application in forest on organic soils: ✓ Increased CO_2 removals in living biomass, dead wood, soil, litter and harvested wood products due to improved growth conditions and additional increment in living biomass
5	Latvia	LVC311	Riparian buffer zone in forest land planted with black alder	Potential benefits of improved planting of black alder in riparian buffer zone: ✓ Reduced GHG emissions from soil due to improvement of water regime by mounding and establishment of network of shallow furrows to drain exceeding surface water ✓ Reduction of risks associated with natural disturbances in forests with wet organic soils ✓ Accumulation of CO_2 in living and dead biomass, soil and litter and replacement effect of forest biofuel and harvested wood products
6	Latvia	LVC309	Semi-natural regeneration of clear-felling sites with grey alder without reconstruction of drainage systems	Potential benefits of forest stand regeneration without reconstruction of drainage systems (from naturally wet or rewetted organic soils): ✓ Reduced GHG emissions from soil due to improvement of water regime by mounding and

				establishment of network of shallow furrows to drain exceeding surface water ✓ Reduction of risks associated with natural disturbances in forests with wet organic soils ✓ Accumulation of CO_2 in living and dead biomass, soil and litter and replacement effect of forest biofuel and harvested wood products
7	Latvia	LVC306	Agroforestry - fast growing trees and grass	Potential benefits of agroforestry: ✓ Increased CO_2 removals in living biomass and soil ✓ Reduced GHG emissions from soil and replacement effect of woody and herbaceous biofuel and harvested wood products
8	Latvia	LVC310	Fast growing species in riparian buffer zones	Potential benefits of fast-growing species in riparian buffer zones: ✓ Increased CO_2 removals in living biomass and soil ✓ Replacement effect of woody and herbaceous biofuel and harvested wood products ✓ Avoided nutrients leakage from farmlands
9	Latvia	LVC301	Conversion of cropland used for cereal production into grassland considering periodic ploughing	Potential benefits of cropland conversion to grassland: ✓ Reduced GHG emissions from soil ✓ Increased carbon stock in soil and below-ground biomass ✓ Reduced risks of nutrient leaching and soil erosion
10	Latvia	LVC305	Controlled drainage of grassland considering even groundwater level during the whole vegetation period	Potential benefits of controlled drainage: ✓ Reduced GHG emissions from organic soils due to reduced fluctuations of groundwater level ✓ Reduced leaching of nutrients to surface water bodies ✓ In summer drought additional water is available to meet crop demand ensuring higher carbon inputs into soil
11	Latvia	LVC304a	Introduction of legumes in conventional farm crop rotation	Potential benefits of legumes in conventional crop rotation: ✓ Reduced N_2O emissions from soil reported in agriculture sector because of avoided mineral fertilizer application and gradual nitrogen input by symbiotic organisms ✓ Increased carbon input with plants ensuring increased soil carbon stock
12	Latvia	LVC313	Strip harvesting in pine stands	Potential benefits of strip harvesting: ✓ Reduced CH_4 and N_2O emissions from soil due to avoiding of increase of the groundwater level after harvesting in comparison to clear-felling
13	Latvia	LVC312	Forest regeneration (coniferous trees) without reconstruction of drainage systems	Potential benefits of forest regeneration with coniferous trees without reconstruction of drainage systems: ✓ Reduced GHG emissions from soil due to improvement of water regime by mounding and establishment of network of shallow furrows to drain exceeding surface water ✓ Reduction of risks associated with natural disturbances in forests with wet organic soils ✓ Accumulation of CO_2 in living and dead biomass, soil and litter and replacement effect of forest biofuel and harvested wood products
14	Finland	FIC301	**Continuous cover forestry on peatland.** Selective felling without	Potential benefits of continuous forest cover forestry practices:

			full ditch network maintenance. Conventional clear cut and uncut plots are used as comparison. Three sites in monitoring at South Finland.	✓ Lower impact to environment conditions in forest stand ✓ Remaining tree stand evapotranspiration controls soil water-table ✓ Reduced/no need for ditch network maintenance ✓ Reduced change in soil CO_2 emission after harvesting ✓ Reduced inputs of water and plant nutrients to surface water bodies
15	Finland	FIC302	**Shifting to continuous cover forestry on peatland.** Forest regeneration following harvesting of overstorey. Conventional clearcut + ditch mounding + planting, and uncut forest are used as comparison. Three sites in monitoring at South Finland.	Potential benefits of continuous forest cover forestry practices: ✓ Lower impact to environment conditions in forest stand ✓ Remaining tree stand evapotranspiration controls soil water-table ✓ Reduced/no need for ditch network maintenance ✓ Reduced change in soil CO_2 emission after harvesting ✓ Reduced inputs of water and plant nutrients to surface water bodies
16	Finland	FIC303	**Shifting to continuous cover forestry on peatland.** Forest regeneration following small gap harvesting and natural regeneration. Spruce shelter tree stand with natural regeneration is used as comparison. Two sites in monitoring at North Finland.	Potential benefits of continuous forest cover forestry practices: ✓ Lower impact to environment conditions in forest stand ✓ Remaining tree stand evapotranspiration controls soil water-table ✓ Reduced/no need for ditch network maintenance ✓ Reduced change in soil CO_2 emission after harvesting ✓ Reduced inputs of water and plant nutrients to surface water bodies

Greenhouse gas monitoring methods

There are two main (dark) closed chamber methods used for monitoring GHG fluxes between soil and the atmosphere in field conditions. In both closed chamber methods, a known area and volume of airspace on top of the monitored soil surface is closed by a chamber headspace, GHG concentration development is followed inside the chamber over time (i.e., deployment period), and GHG flux rate is determined by combining information on the closed soil surface area, the volume of the closed airspace, and the GHG concentrations over deployment period. The practical difference between the methods is timing between the air sampling event at the field and GHG gas concentration analysis that provides the final GHG flux reading. The first method involves a series of individual air samples collected during deployment time from the closed chamber at the field, storing the samples for transportation, subsequent GHG concentration analysis in the laboratory and calculus of the GHG flux (hereafter referred also as method-1). The second method involves closing the monitored airspace by closed chamber and circulation of air between the closed chamber and GHG analyzer, and instant GHG concentration analysis and flux readout provided at the field (hereafter referred also as method-2). The first method is often referred to as the ‘static chamber method’ and the latter as ‘dynamic chamber method’.

Traditionally the static chamber method has been more practical because (1) the GHG concentration analysis is based on common laboratory equipment and the analytical method by gas chromatography, and (2) several important GHG species including CO_2, CH_4 and N_2O can be analyzed from the same gas sample, which usually makes the cost per sample affordable. The downside of the method is general slowness and labor intensiveness (e.g., long deployment time at air sample collection especially for CH_4 and N_2O, potentially long duration of time in sample transport/storage prior to the analysis by gas chromatography) before the actual GHG fluxes can be calculated.

The first portable gas analyzers suitable for use in field conditions in growing season and using the dynamic chambers were for CO_2 data collection (trademarks such as ADC, EGM, Licor, etc.). Monitoring multiple GHG species (CO_2 and/or CH_4 and/or N_2O) has become possible in field conditions only recently due to technical development in instrumentation and because of the price of analyzers (e.g., Licor, Picarro, Gasmet, etc.) have gradually become more affordable. The key benefit of this method (in comparison to static chambers) is speed due to short deployment time and instantly available flux readout(s) for GHG(s). Instantly available GHG flux readout at the monitoring location allows renewed flux monitoring if the technical failure (e.g., leakage in the chamber) occurs. Short deployment time makes it possible also to collect GHG data from a higher number of monitoring points/conditions compared to the static chamber method. The downside of the method includes the high price of analyzer, still somewhat developing techniques for use in demanding weather/climate conditions and sites, and analyzer-specific limitations in GHG species included.

In the LIFE OrgBalt project sites GHG fluxes will be monitored by both above-described closed chamber methods. ‘Method-1’ sampling was started in 2020 in Finland and at the end of the year first regular sampling round was performed also in Estonia and Latvia. In Lithuania regular sampling will start in beginning of 2021.

‘Method-1’ on-site gas sampling using opaque closed static chambers (e.g., Hutchinson and Livingston, 1993; Ojanen et al., 2010) will be used to measure total ecosystem respiration (R_{total} CO_2), CH_4 and N_2O. Collars (Ø 50 cm) in 5 replicates will be pre-installed to soil to form permanent bases for chambers. Vegetation within the collar enclosed soil surfaces is not disturbed. Collars in cropland- and grassland sites will be temporarily removed during field management operations. In grasslands and croplands transparent closed dynamic chamber on these collars will be used to assess net ecosystem exchange (the same chambers are used for infra-red gas analyser, see ‘Method-2’) during growing period. During a 40-60 minute (depending on the volume of the chambers) long deployment period, four air samples will be drawn from the cylindrical chamber headspace into pre-evacuated glass bottles. CH_4 and N_2O concentration will be analysed in the lab using gas chromatography for subsequent analysis of soil net gas exchange determination for these gases. Method-1 is used in every site during winter as this method is not so demanding for weather conditions.

‘Method-2’ will be used for in-situ CO_2 flux monitoring by using closed dynamic chambers (Järveoja et al., 2016; Ojanen et al., 2012). Concentration change and flux will be determined using portable gas analyser (e.g. IRGA, Licor). On each site, 9 permanent flux monitoring points will be established for heterotrophic soil CO_2 emissions monitoring. To prevent autotrophic root respiration contributions into CO_2 fluxes, flux monitoring enclosed surfaces will be trenched and root-ingrowth preventing cloth will be installed beforehand (belowground litter deposition and carbon loss as CO_2 will be determined separately). All monitoring surfaces will be kept free from litter during monitoring (litter deposition and emissions from litter decomposition will be determined separately). Soil respiration chamber will be set gas-tightly on the soil surface and during each flux measurement, CO_2 concentration and temperature inside the chamber will be recorded over a deployment period up to 3 min. Higher number of monitoring points is reserved for CO_2 monitoring is based on high importance of this specific greenhouse gas from drained organic soils (IPCC 2014). This approach yields to a sufficient amount of observed data of CO_2 emissions, keeping in mind that several different processes both spatially and temporarily are contributing to the emission (Hiraishi et al., 2013), and monitoring by IRGA allows relatively fast CO_2 flux data collection.

Fluxes of CO_2, CH_4 and N_2O will be calculated from change in gas concentration in the chamber headspace over time, adjusted by the ground area enclosed by the collar, volume of chamber headspace, air density and molar mass of gas at measured chamber. Flux monitoring at each site will be continued on monthly basis for 24 months. The same sampling and flux calculation methods are applied both for reference and demo sites but also the same time period is used for sampling to guarantee comparability of data between the sites and countries.

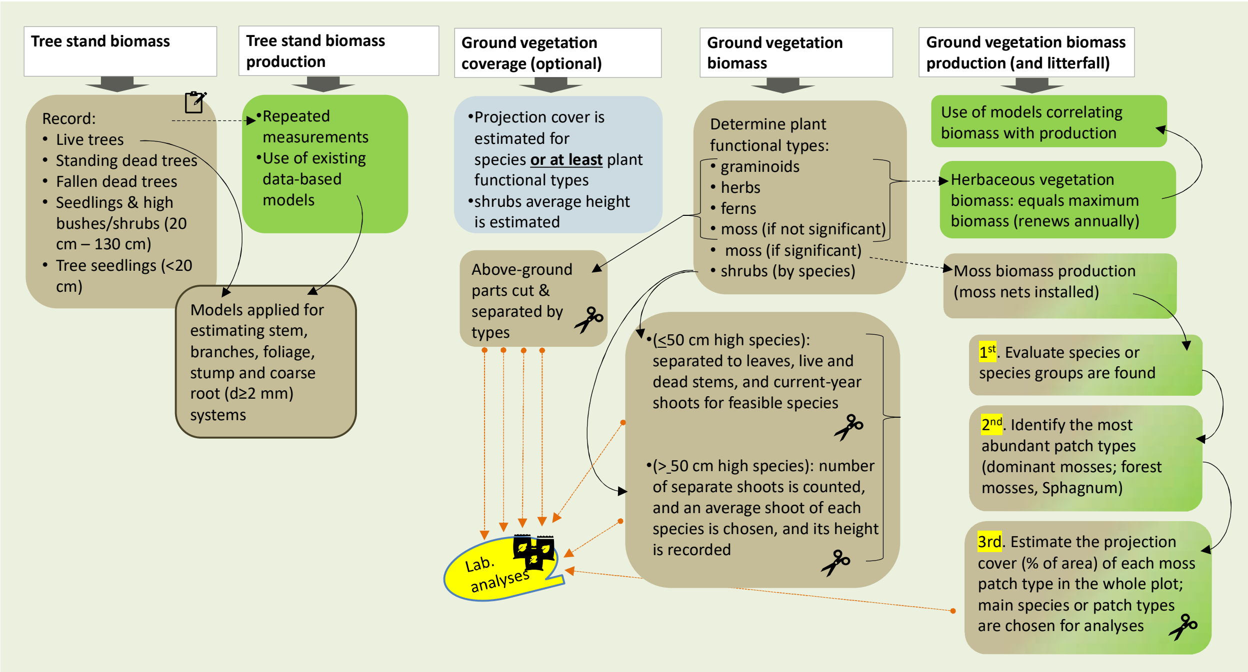
As final outcome, gaseous flux monitoring data will provide directly soil net balance for CH_4 and N_2O fluxes over monitoring period. For estimating soil net CO_2 flux at all monitoring sites, heterotrophic CO_2 fluxes estimated by the 'method-2' will be combined with relevant biomass-based C-flux flows for providing complete soil net CO_2 flux. In addition, soil net CO_2 balance in non-forested sites will be estimated from modelled net ecosystem CO_2 exchange based on in-situ collected data.

Biomass-related measurements quantifying annual production

Carbon fluxes mediated by vegetation will be estimated by measurements of plant biomass and production (Ojanen et al., 2013; Uri et al., 2017). Tree stand above-ground and below-ground biomass (coarse root) estimation will be based on measuring the tree stand diameter distribution (breast height diameter) of all trees on the sample plot, and further parameters (e.g., tree height and length of the live crown) for sample trees. Sample tree data forms complementary set of variables for all trees. Biomass of different stand components (stems, branches, foliage, stump and coarse root systems) will be estimated with allometric functions that use breast height diameter, either alone or together with the complementary variables, as explanatory variables (see Figure 2). Such functions are available for all our common forest tree species (e.g., Zianis et al., 2005; Liepiņš et al., 2017). Biomass production estimation will be based on annual diameter growth of measured sample trees. The growth data will be used to construct diameter distributions, and the complementary set of variables, for the stand in consecutive years. The allometric functions will be fitted into these data sets, and the annual biomass production will be estimated as the difference between biomass values of consecutive years. Values will be transformed per square meter using sample plot area.

The above-ground biomass of the ground vegetation will be measured by harvesting, drying and weighing the above-ground vegetation of small plots at the time of peak biomass in late summer 2021 and 2022 (see Figure 2). The samples will be separated into plant functional types (shrubs, graminoids, forbs, mosses, as applicable). For deciduous shrubs, the biomass will be separated into leaves and stems. For all shrubs, current-year shoots will be separated. Shrub stem radial growth will be estimated using literature data for plots with substantial shrub layer. Otherwise, deciduous leaves and current-year shoots will be considered as annual biomass production. For herbaceous plants, total biomass will be considered as annual above-ground production. Values will be transformed per square meter using sample plot area. Existing data on correlations between biomass and annual production rates in different species will be applied where possible, and further developed in forest sites to ease laborious harvesting, separation, and drying work.

Fine root biomass (<2mm) will be estimated from volume-exact soil cores, analysed down to the rooting zone lower limit in 10-cm sections (see Figure 2). End of live-root occurrence will be confirmed from the samples. Roots will be separated from soil by hand, washed free of soil, dried and weighed, and soil bulk density will be used to generalize root mass per sample volume to values per square meter. Fine-root production will be estimated by the ingrowth-core method modified for peat soils (Laiho et al., 2014; Bhuiyan et al., 2017), or the root mesh method (Uri et al., 2017) for annual plants. The amount of ingrown roots represents fine-root production over the 1-2 years long incubation period, which will be generalized into annual production per square meter. Pilot studies suggest that two years incubation time is needed for sites with perennial vegetation (Bhuiyan et al., 2017 and unpublished data). In the root mesh method, roots grown through the strips during incubation period and thereafter measured for a known volume both sides of the strip represent production. This simpler method is enough where branching and radial growth of existing root systems need not be considered. Fine-root turnover (litter input) will be estimated as production per biomass. Roots in both biomass and ingrowth core samples are separated into tree and ground vegetation roots to the extent possible; this task is labour intensive and requires expertise.



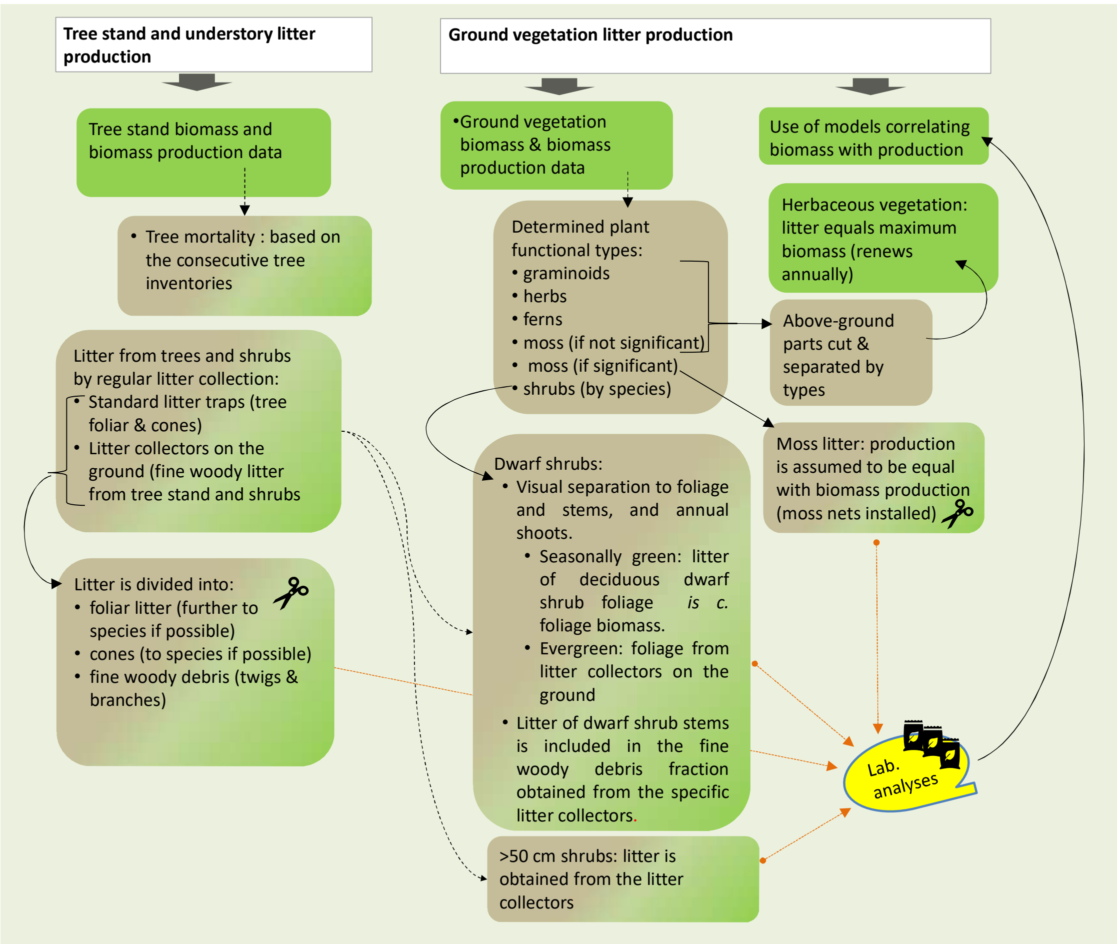


Figure 2. Outline of planned aboveground biomass and biomass production determination (upper graph) and aboveground litter production (lower graph) in tree, understory and ground layers in Life OrgBalt.

Tree stand biomass determination is planned to take place in 2021 for respective sites in the Baltic states, and pre-existing biomass production measurements at demo sites in Finland will be supplemented on the basis of recurrent measurement schedule. ***Ground vegetation coverage*** measurements and ***ground vegetation biomass*** sampling (biomass and biomass production samples) were made in Finland 2020, and biomass samples are now drained and partly analysed. Ground vegetation coverage measurements and ground vegetation biomass sampling in the Baltic states are planned to be started in 2021 by utilizing on-site harvested samples, which are possibly supplemented modelling-based approach to ease large workload involved. As a part of ground vegetation biomass monitoring, moss nets were installed on forest sites with abundant moss coverage during autumn 2020 in all countries. In Finland, during past years installed moss nets were harvested 2020 and the materials are now in analysis. ***Fine root biomass*** samples (soil cores) have been collected from the Finland sites in 2020 and are stored for analysis. Fine root biomass sampling has not yet started in the Baltic states. ***Fine root production*** measurements are to be started in the Baltic states 2021, and in Finland incubation started at 2 sites 2020 and samples from previously stated incubation at one site were harvested autumn 2020 and are now in preparation.

Carbon inputs with dead biomass and carbon loss rates

Estimates of current carbon stock in litter and dead wood will be obtained by the area-based sampling in each site. For forested sites, annual tree mortality estimates will be based on monitoring data from other projects, or tree mortality models (e.g., Jutras et al., 2003), where applicable. Carbon input with the annual above-ground litter from perennial plants will be based on a repeated collection of litter from litter traps of known area set at the sites (e.g., Ojanen et al., 2013; Uri et al., 2017), following the litter classification and analysis by methodology defined for ICP forest monitoring (see Figure 3). For annual plants, the annual biomass production equals also the amount of litter input. Annual fine-root litter input rates will be based on the production/biomass ratio as described in previous chapters.

Decomposition of these C pools will be estimated using decomposition models, separately for the coarse woody debris of on conifer and deciduous trees (e.g., Pearson et al., 2017; Tuomi, Rasinmaki, et al., 2011; Tuomi et al. 2011a; Pearson et al., 2017), and fine litter (e.g., Strakova et al., 2012; Tuomi et al., 2011a) in different climatic conditions (see Figure 3). The litterbag method (Strakova et al., 2012) may be used for estimating litter decomposition rates in cases where no applicable models exist (see Figure 3).

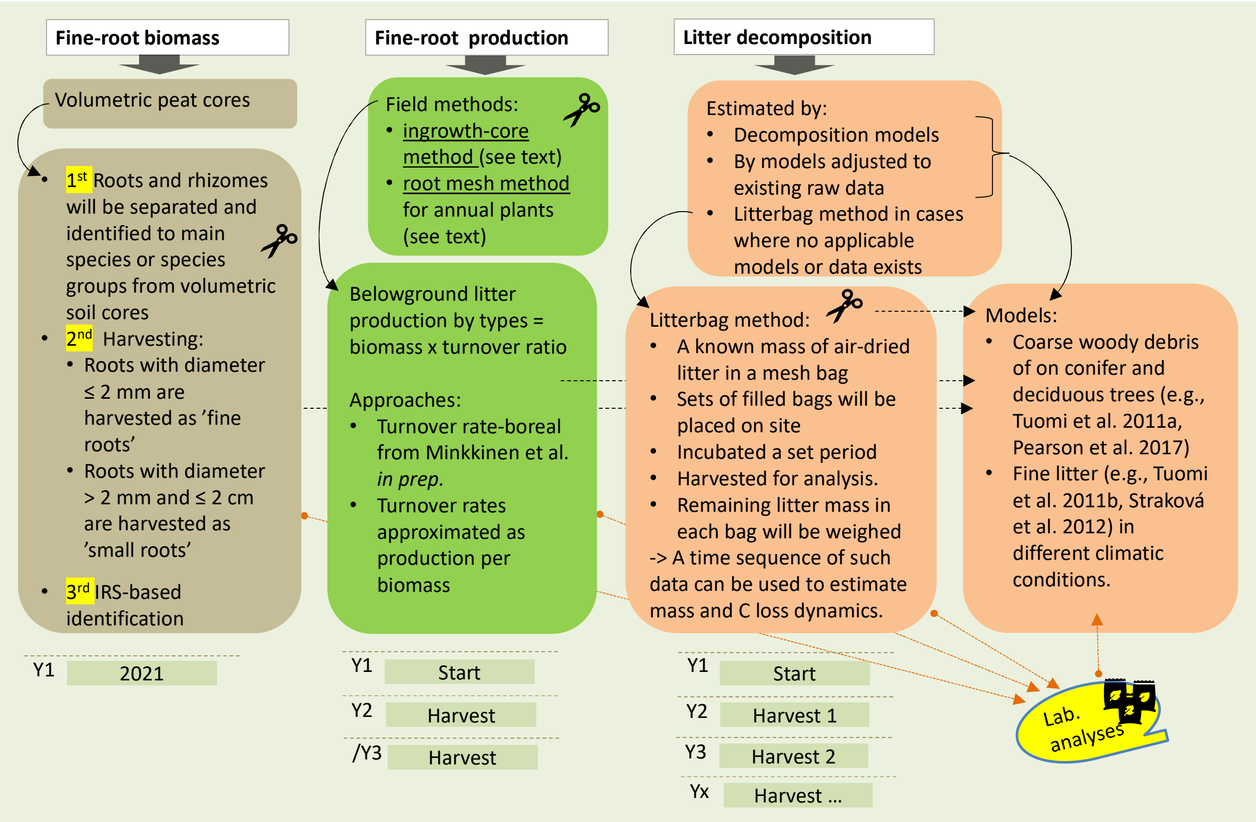


Figure 3. Outline of planned belowground fine-root biomass and biomass production determination and belowground decomposition determination in LifeOrgBalt.

Litter traps colleting litterfall from trees and at ground level have been set at forest sites during autumn 2020 in all partner countries. Existing litter collection in Finland were upgraded according to Life OrgBalt standard and previous year materials are currently in analysis. ***Litter decomposition*** study materials have been collected in selected sites in 2020 (collection continued 2021) and decomposition stud incubations are planned to be started in 2021. Pre-existing materials and data (from former applicable studies) are currently surveyed for possibilities to use in decomposition modelling.

Characterizing soil microbial communities

Soil and sediment sampling will be performed in each Life OrgBalt site next to the GHG monitoring plot for the microbial community structure analysis. The chosen main strategy is adjusted according to the data on carbon dioxide emissions on these drained soils. Soil samples will be taken from only one depth below the litter layer (10 x 10 x 10 cm sample) in soil profile. At each site six GHG monitoring plots exist; three in a trenched area where root in-growth is prevented by a mesh and three in an untrenched area. Trenching is performed to measure heterotrophic respiration as CO_2 flux.

DNA extraction will be performed from all sample materials. The bacterial and fungal community structure will be assessed with amplicon sequencing targeting the 16S and ITS regions, respectively. As a deviation from the proposal plan, the main focus will be on the microbial decomposer community involved in in the CO_2 emissions because (1) it is likely to be the main GHG gas species emitted from these primarily drained nutrient rich organic soils, and (2) it would be challenging to sample soil profile depths to below the ground water level necessary for studying methanogens and methanotrophs. As the set of GHG monitoring sites are quite recently fixed, there are yet no data on soil characteristics, water table depths, or GHG flux data available for most of the sites Further plans on data management remains to be made later.

As described for the whole procedure in Kosunen et al. (2020) the DNA is extracted from the samples using NucleoSpin soil kit (Macherey Nagel, Germany). Nanodrop One (Thermo Scientific) is used to measure DNA concentrations. ITS2 region for fungi and V4 region of 16S SSU rRNA for bacteria are amplified by polymerase chain reaction (PCR) and the fragments are then sequenced with the MiSeq platform (Illumina) by utilizing the MiSeq v3 kit. PipeCraft 1.0 pipeline software is used for quality filtering as well as removal of artifacts, primer-dimers and primers from the raw 16S rRNA and ITS sequence reads. After assembling of paired end reads and a two-step quality filtering, an OTU table is created from the sequence reads. OTUs are then annotated taxonomically using BLAST and a reference ITS2 database (sh_genral_release_dynamic_01.12.2018.fasta) from UNITE and a 16S rRNA database (SILVA_123_SSURef_Nr99_tax_silva.fasta) from SILVA to find representative fungal and bacterial sequences, respectively. After quality filtering, functional information of fungal guilds of OTUs are derived from FUNGuild.

Microbial community study is currently in planning phase. Timing of sample collection will be around the peak growing season in late August or early September 2021. Sampling guidance will be provided for consortium field teams. Samples will be transferred into cool boxes and stored in refrigerator at 4°C before sending to Luke at earliest possible time.

Soil screening with infrared spectroscopy (IRS)

IRS has long been applied in characterization of samples with complex chemical composition, including peat (Holmgren and Nordén, 1988; Krumins et al., 2012; Hayes et al., 2015; 2015; Straková and Laiho, 2016). Infra-Red (IR) radiation is electromagnetic radiation with longer wavelengths than those of visible light. In this method, an IR beam of a known range of wave numbers is passed on the sample, and the absorption of the radiation by the sample is registered for defined wave number intervals. The power of IRS is based on each chemical bond present in a sample absorbing IR radiation in a specific manner that depends on the nature of the bond. Thus, an IR absorbance spectrum, showing for each wavelength or wave-number the proportion of radiation absorbed by the sample, shows the relative abundance of different chemical bonds in the sample. IR spectra thus summarize the whole chemical composition of the sample. The spectra can either be used for direct interpretation of the absorbance intensities at different wave-lengths, or be reduced into a smaller number of variables that contain summarized information on the systematic variation in the spectra by, e.g., Principal Component Analysis or other multivariate methods (Adamczyk et al., 2016). Such summary variables may then be used as predictive variables (e.g., Vávrová et al., 2008), in our case for GHG emissions. These approaches can be combined by first seeking for the characteristics of the spectra that have the best predictive power, and then interpreting them (Adamczyk et al., 2016). IRS is a fast and cheap method, once the spectrometer is available, as is for this project in both Luke and UT. Lack of scientifically approved, simple and inexpensive methods for characterization of peat properties affecting GHG emissions from organic soils is one of the main challenges hampering the development of unified GHG accounting and projections models for organic soils. The LIFE OrgBalt project will test IRS as such solution for peat and soil samples collected in cool temperate moist climate zone in forest land, cropland and grassland. In parallel peat samples collected previously in the LIFE REstore project (from 42 GHG measurement and demo sites) will be used to cover full spectrum of peat properties – from nutrient-poor sphagnum peat to fertile peat of mesotrophic bogs. The project will ensure comparability with GLOSOLAN network by utilization of the GLOSOLAN specifications-based equipment and procedures. If the comprehensive description of soil chemistry with IRS proves to have predictive power for soil GHG exchange, the methodology could revolutionize the estimation of these emissions.

Soil samples collected in for soil analyses (next chapter) will be utilized for IRS trials in parallel to implementation of conventional methods. IRS data will be compared with GHG fluxes, as well as with soil properties - pH, N, P, K, Ca, Mg, C and ash content. Mineral and peat soil will be treated similarly.

The activity will be implemented in 2021 and 2022 after collection and primary processing of soil samples. Results will be published in peer reviewed scientific article until completion of the LIFE OrgBalt project.

IRS study is currently in planning phase. Timing of sample collection will be around the peak growing season in late August or early September 2021, and it is planned to take place at same time as soil sampling to soil analyses and sampling to microbial community study.

Soil and water analyses

Comprehensive evaluation of soil properties down to 100 cm depth will be done in all gas fluxes measurement plots during the establishment of the reference and demonstration sites. Soil properties will be implemented once during the project implementation, in 2021-2022. Soil sampling and analyses will be performed according to ICP Forest guidelines (Cools and de Vos, 2010; Konig et al., 2010). Methodology providing comparable results. Sampling will be done in 3 repetitions in every reference and demo site or using method providing comparable results. Good procedure is sampling at north and south from gas measurement sites, as close as possible to gas sampling & measurement sites. Sampling sites will be located in flat area representing average conditions in a reference or demo site. 100 cm3 undisturbed soil samples will be collected at 0-10, 10-20, 20-30, 30-40, 40-50 cm depth and disturbed samples at 50-75 and 75-100 cm depth. After collection samples will be transferred to plastic bags with labels containing information on project, sampling plot, repetition, depth and date. Additionally, litter samples (10 x 10 cm to the whole depth) will be collected nearby soil sampling sites in forest land. Small pits can be dug to collect samples if sampling with auger is not possible. Litter samples in the field or in laboratory should be cleaned from green (living) parts of plants.

Soil and litter samples will be collected in spring and summer, 2021 or 2022. However, sampling period is not critical as far as total content of elements is determined.

After collection samples will be transported to LSFRI Silava laboratory of Forest environment and air dried. Then all samples will be dried at 105ºC degrees, weighed to determine bulk density, milled and screened through 1 mm sieve, samples for elemental analyses will be milled and sieved through 0.25 mm sieve. After preparation of samples following parameters will be determined: bulk density, pH, N, P, K, Ca, Mg, C and ash content. Parameters which will be determined in soil and reference methods are provided in Table 2.

Table 2: Parameters and reference methods of soil analyses

No.	Parameter	Reference method	Application1
1.	Sample pre-treatment	ISO 11464	IR
2.	Soil Moisture Content	ISO 11465	IR
3.	Bulk Density	ISO 11272 (adopted to organic material)	I
4.	pH	ISO 10390	IR
5.	Organic Carbon (C)	ISO 10694	I
6.	Total nitrogen (N)	ISO 13878	IR
7.	Aqua regia extractable phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg)	ISO 11466	IR2
8.	Ash content	ISO 1171	I

Water samples (0.5 L per piezometer per time) will be collected from piezometers during every site visit (monthly base in average), simultaneously with gas sampling. Sampling will be done from one of piezometers, the other should be used for continuous measurement of water level, and additional 2 piezometers should be used for manual water level measurement during site visits, if sample plot is split into subplots. Water samples after collection will be transported in cold camera and stored in freezer at low temperature (4ºC). Once per month all samples should be transported to Latvia for analyses. This can be done simultaneously with transportation of gas bottles for gas analyses. At LSFRI Silava following parameters will be determined in water N total, NO_3^-, P, K, Ca, Mg, DOC). Additional parameters, e.g., Hg may be considered in case of additional funding to determine linkage between environmental conditions and Hg outputs into water. Parameters which will be determined in water samples and reference methods are provided in Table 3.

Table 3: Parameters and reference methods of water analyses

No.	Parameter	Reference method
1.	Sample pre-treatment	ISO 10523, ISO 7888
2.	**pH**	ISO 10523
3.	Electrical conductivity	BS EN 27888
5.	Total N, NO_3^-, TOC	ISO 10304-1, ISO 12260, BS EN 1484

6.	Dissolved K, Ca and Mg	ISO 7980, ISO 9964-3
7.	Total P	ISO 6878

The results of the analyses will be used to determine possible correlations and covariations with GHG fluxes, particularly, after the proposed actions will be implemented in the project demo sites. Water properties will be used as additional parameters to increase accuracy of the elaborate GHG emission models and to improve ability to predict GHG fluxes under different management scenarios and land uses.

Modelling

The Susi peatland simulator is aimed for application in boreal and tropical climate zone to calculate growth response on drainage of organic soils, including estimation soil carbon losses. Susi peatland simulator is based on assumption that forest growth is limited by accessibility of nutrients, which are released during decomposition of organic matter. Increased groundwater level is slowing down decomposition of organic matter and availability of nutrients, resulting in reduction of growth of trees and carbon losses. Susi peatland simulator is aimed at parametrisation of these variables. The main modelling aim is to upgrade SUSI peatland simulation for use in projecting CC scenarios and make the software useable within the Life OrgBalt region. Furthermore, SUSI will be delivered as open-source software to be readily and widely adaptable for drained organic soil research and land use studies.

The SUSI peatland simulator development in ongoing. The effort placed on this task has been increased by the addition of postdoctoral researcher Jani Anttila to the project. Considerable effort is now made in improving the accessibility of the simulator. This includes writing documentation, user instructions, improving the readability of model output, creating well explained example use cases, as well as improving the actual user interface to the simulation code via Jupyter notebooks and from the command line. The model has been also made publicly available on Github at https://github.com/annamarilauren/susi so that researchers and developers can access the source code and suggest improvements directly to the maintainers.

The current challenge in applying the SUSI model in Baltic countries is generating the appropriate input data. These data need to contain specifics, such as tree biomass partitioning into branches, leaves, roots, etc., which need to be estimated with statistical models appropriate to the site and tree species. More effort and co-operation are currently directed into achieving this task of creating suitable inputs for the model.

Post 2023 impact assessment

A replicability and transferability strategy has been published under action A2 to multiply the impact of the Project results during its implementation and to replicate and transfer its findings after its end, in order to reach a wider audience and implement its results in further sites and regions, other than the Project demo sites.

A key role in this respect is represented by the elaboration of a Simulation model (SM) under action C5. The simulation model will serve as a policy planning / decision support tool for the development of GHG emissions projections at national level and the analysis of the socio-economic impact for 2 scenarios – with and without implementation of CCM measures - with dynamic background information on changes of technical conditions of drainage systems. The elaboration of these models will be possible on the bases of the results of Activities C1 and C2, namely the elaboration of a catalogue of climate change mitigation measures including a socio-economic impact assessment, the improvement of GHG emission factors and of the methodologies for GHG inventory reporting together with the related national reports, and finally the elaboration of mathematical equations and tools for GHG projections from organic soils. The simulation model will be proposed as an evaluation tool to determine the extent to which measures should be implemented in each evaluated country. This will support the development and the evaluation of climate change mitigation measures related projects in the context of the Common Agricultural Policy. The simulation model main targets are policy and decision makers, consultants, non-governmental organizations of farmers and foresters, individual stakeholders (major foresters and farmers). The model will include data on organic soils at national level and the potential for land use change according to the 17 climate reduction scenarios identified in the project. Data on organic soils and their use in each evaluated country will be integrated. Feedbacks from the involved stakeholders will be collected during the dissemination, training and networking activities planned under actions E.2 and E.3, i.e., National workshops, Thematic Workgroup meetings, Networking workshop on national level and Experience exchange visits. Feedbacks will be gathered to improve the developed models as well as to evaluate the results obtained through them, in terms of GHG emissions reductions and the socio-economic impacts under different management scenarios. In addition, the project envisages a total of 10 training seminars -2 for each country - which are planned to be organized at two levels - one for consultants and the other for individual stakeholders, i.e., landowners and managers. During training workshops, the simulation tool will be presented to give a national perspective of the implemented climate change mitigation measures.

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