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AFFORESTATION OF ABANDONED PEAT EXTRACTION SITES WITH SCOTS PINE (*PINUS SYLVESTRIS* L.) AS A SOLUTION OF CLIMATE CHANGE MITIGATION

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Abstract
On a global scale, ambitious climate change mitigation targets are set. By 2050, the European Union is expected to be climate neutral which means that the greenhouse gas (GHG) emissions will not exceed removals. This initiative is also supported by Latvia. For businesses and carbon intensive industries transition to climate neutral economy will be provided by Just Transition Fund. The direction of the peat sector towards climate neutrality will promote research and innovation as well as restoration of peat extraction sites. These are also the objectives of implementing the Just Transition Fund for investments in Latvia. Studies on management of peat soils to improve the calculation of greenhouse gas (GHG) emissions have been carried out in Latvia within LIFE REstore project. The aim of the study is to assess the impact of afforestation of abandoned peat extraction sites with Scots pine (*Pinus sylvestris* L.) on GHG emissions compared to retaining of the existing situation (abandoned peatlands with poorly developed vegetation). Afforestation of degraded peatlands can contribute to significant GHG reduction in wetlands – up to 20% of the net GHG emissions due to wetlands management. The most of the GHG mitigation potential is ensured by accumulation of CO_2 in living biomass.
Key words: afforestation, greenhouse gas emissions, peat extraction sites, climate change.

Introduction

The role of wetlands as a carbon sink has become more important as they contribute to the greenhouse effect and climate change (Quinty & Rochefort, 2003). The important role of peatlands as carbon sinks has been demonstrated by carbon cycle studies (Bāders, 2011). Although natural bogs emit greenhouse gases such as methane, drainage of bogs and peat extraction lead to significant increase in global warming potential and the loss of carbon sinks that have been developed over thousands of years (Quinty & Rochefort, 2003; Kløve *et al*., 2017). The amount of carbon stored in peatlands is closely related to the thickness of the remaining peat layer and the degree of decomposition of the peat, as well as humification processes in the peat (Bāders, 2011). Bogs are types of ecosystem where carbon, along with nitrogen and several other elements, have accumulated as peat formed from plant litter that accumulates in these areas. In the past, bogs covered 5–6% of the surface of continental Europe, half of the bogs in Europe are subject to various land uses, often associated with drainage (Drösler *et al*., 2008). In Latvia, according to the data of the Peat Fund of 1980, the total area of bogs is 6401 km^2 or 9.9% of the country's territory. Peat resources play a significant role in both the conservation of biodiversity and its use in the economy (Jansons, 2016). In Latvia, peat was initially mined in quarries without draining the bogs. At the end of the 19th century and the most of the 20th century, peat was extracted in drained bogs. Today, many of these areas are already overgrown with forests or naturally revegetated. The use of peat generates GHG emissions from peat extraction in the peat extraction area and emissions from the use of peat in agriculture, such as forestry, forest plant growing, horticulture, livestock litter, and energy from peat incineration. In the category of weatlands in the GHG inventory, emissions are calculated from peat extraction areas where peat extraction takes place or has taken place (ha) and the amount of peat extracted (t), distinguishing between agricultural and energy use (Cabinet of Ministers, 2020). In wetland category, changes in carbon stock are also calculated, in the areas with woody vegetation that do not meet the definition of forest land (living and non-living biomass) and GHG emissions from soils in areas renaturalized after peat extraction by purposefully restoring the original moisture regime or the areas, which were flooded. GHG emissions from wetlands in 2018 were 1708.92 kt CO_2 eq. (Skrebele *et al*.,2020). It is important to reduce GHG emissions by avoiding the development of new peat deposits as much as possible, first of all, evaluating the possibility of peat extraction in historical peat extraction sites, where peat extraction no longer takes place, but recultivation is not perforemed (Cabinet of Ministers, 2020). Peat extraction no longer takes place in such areas, but these areas are not able to regenerate naturally as bogs or other ecosystem. In the cutaway peatlands, GHG emissions are even more negative in the context of GHG emissions without recultivation and the creation of new or expanded peat extraction sites (Priede & Gancone, 2019). Evaluating the experience gained and accumulated in the peat extraction sector and literature, as well as information provided by industry specialists and experts, the types of recultivation suitable for Latvian conditions are: renaturalization, afforestation, berry plantations – blueberries and cranberries, cultivation of paludicultures – growing of bog plants for biomass production, creation of water reservoirs and growing of perennial grasslands (Cabinet of Ministers, 2020; Priede & Gancone, 2019). Within the scope of the LIFE REstore project "Sustainable and responsible management and re-use of degraded peatlands in Latvia", areas affected by peat extraction have been identified with a total area of about 50 thousand hectares, of which about 15 thousand ha are peat extraction (30%), about 17 thousand ha (34%) peat extraction has taken place or is undergoing reclamation (natural regeneration, flooding and flooded areas, forests, grasslands or berry plantations) and approximately 18 thousand ha (36%) are degraded areas subject to recultivation. In total, for 18 thousand ha of degraded, non-reclaimed peatland areas and the best suitable recultivation method for these areas has to be chosen (Priede & Gancone, 2019). The purpose of reclamation is to ensure the continued full use of mining sites after the completion of mining, to prevent threats to human life and health and the environment, and to promote integration into the landscape (Cabinet of Ministers, 2020). The types of recultivation of peat extraction sites that have been determined in a general way, in accordance with the regulatory enactments in force in Latvia, are renaturalization (restoration of the environment characteristic of a bog), preparation for agricultural use (berry plantations), preparation for use in forestry, creating water bodies for recreation (Cabinet of Ministers, 2012). Forests is the environment, where significant part of the organic matter is preserved in the form of peat for a long time. By mobilizing the energy stored in the peat layer, the productivity of wood increases several times, additional amounts of CO_2 are captured and accumulated in living biomass. Forests contribute to the reduction of the greenhouse effect by increasing the stock of wood, accumulating carbon and releasing the oxygen necessary for the existence of living organisms. Approximately 700,000 ha of forests out of 1.5 million ha of swampy and wet forests have been reclaimed in Latvia (Indriksons & Palejs, 2005; Zālītis, 2006). Most of the CO_2 emissions in Latvia are generated in organic soils, more than half of these emissions are formed in forest lands, but the emissions from soil due to wetland management are an important source of emissions, excluding GHG emissions from peat extraction (Priede & Gancone, 2019). Average GHG emissions and CO_2 removals depend on the climatic region and soils fertility. CO_2 and N_2O emissions from drained forest soils account for less than 10% of net emissions from forest stands, while CO_2 sequestration in living biomass accounts for 35% of total CO_2 sequestration in forest stands. According to the interpretation of the 2013 Supplement to the 2006 IPCC Guidelines, for all organic soils in Latvia the same emission factors have to be used, regardless of whether the area is drained or not, which means that in terms of emissions, forest stands with drained and naturally wet soils have the same emission factors. CO_2 emissions from soil in forests on non-drained mineral soils and forests on drained organic soils are 2.6 tons of CO_2-C per year, direct N_2O emissions from soil are 2.8 kg N_2O-N ha^{-1} per year (4.4 kg N_2O ha^{-1} or 1.3 tons CO_2 eq.), CH_4 emissions from ditches are 217 kg CH_4 ha^{-1} per year (Lazdiņš, 2015).

The most important measure to offset GHG emissions from deforestation is afforestation (Lazdiņš, 2015). Forestry is an advantageous opportunity for recultivation of developed peat deposits, as it has both commercial and aesthetic values. Relatively new recultivation practice is afforestation of peat deposits; therefore, we are still looking for the most suitable tree species for afforestation, as well as the most suitable fertilizers that would ensure successful recultivation of the developed peat deposits in the long term (Bebre & Lazdiņa, 2017). The most suitable tree species for afforestation of peat extraction sites are pine and birch (Liepiņš, Baders, & Liepa, 2009). Afforestation ensures the accumulation of CO_2 in living and non-living biomass, litter and soil (Progress report under…, 2017). According to studies in Finland and Sweden, CO_2 emissions from afforested peat deposits average 1397 g m^{-2} per year (1008–1756 g m^{-2} per year), CH_4 emissions are – 0.05 g m^{-2} per year (-0.03-0.09 g m^{-2} per year) and N_2O emissions are 0.15 g m^{-2} per year (0.02–0.75 g m^{-2} per year) (Mhkiranta *et al*., 2007; Alm *et al*., 2007).

The average additional growth of a tree trunk during the rotation period using improved planting material in reforestation is 43 m^3 ha^{-1} (Progress report under…, 2017). In addition, the sequestration of CO_2 in living biomass using selected planting material in reforestation is on average 50 t ha^{-1} in forest management cycle. The direct impact of the selected material on the Latvian scale can reach 104 million tons of CO_2 in 75 years or 138 Gg of CO_2 per year (Lazdiņš, 2015). Afforestation of developed peat deposits is a technically easily feasible practice and the main wood products are wood chips, pulpwood and roundwood (Makovskis *et al*., 2019). In sustainable forestry, CO_2 sequestration is in balance with long-term forest growth, and felled timber form the forest can be seen as a substitute for natural extinction, which would otherwise be the same. Growing trees act as a carbon sequestration system, providing physical storage of carbon that was previously released into the atmosphere (Pingoud *et al*., 2003; Sathre & O'Connor, 2010). In managed forests, carbon is retained in the resulting building materials and furniture, and the use of wood as a fuel saves the use of fossil fuels and thus eliminates additional CO_2 emissions (Kļaviņš & Zaļoksnis, 2016).

Wood products have been identified as a significant source of CO_2 removals, but may be affected by reduced logging or a deterioration in the structure of the timber being harvested (higher proportion of biofuels), as this carbon sink may become a significant source of CO_2 emissions in the future (Lazdiņš, 2015). Wood products reduce CO_2 emissions because wood products are carbon sinks and can replace carbon-intensive materials. Each cubic meter of wood captures 0.9 t of CO_2, which is not released into the atmosphere during the initial life cycle of wood products, as well as after the wood products are recycled and reused (Pingoud *et al*., 2003). Each cubic meter of wood used to replace other building materials reduces CO_2 emissions to the atmosphere by an average of 1.1 t of CO_2, plus 0.9 t of CO_2 accumulated in wood, then a total of 2 t of each cubic meter of wood (Beijere *et al*., 2006).

The aim of the study is to assess the impact of afforestation of abandoned peat extraction sites with Scots pine (*Pinus sylvestris* L.) on GHG emissions compared to retaining of the existing situation (abandoned peatlands with poorly developed vegetation).

Materials and Methods

During the LIFE REstore project "Sustainable and responsible management and re-use of degraded peatlands in Latvia" research work was carried out to replace the emission factors offered by Guidelines of GHG Inventories of Intergovermental Panel on Climate Change (IPCC) with nationally applicable emission factors and activity data. Ecosystem carbon dioxide (CO_2) exchange – measurements were taken, using transparent chamber method, which enables determination of the CO_2 removals caused by photosynthetic activity of ground vegetation (Salm *et al*., 2012) and the opaque chamber method for determination of CH_4 and N_2O fluxes (Hutchinson & Livingston, 1993). Gas samples were collected in 50 ml glass flasks previously vacuumed in the lab. Gas analyses were done using a gas chromatography method. CO_2 fluxes in transparent chamber were determined using EGM-5 analyser. Results of gas analyses were subjected to quality control, by verifying if changes of gas concentrations are linear during 60 min. period (samples were taken 4 times with 20 min. interval at each sampling cycle using opaque chambers). Low quality data series (R^2 value of 4 measurements is below 0.95 for CO_2) are excluded from further analysis. Litter input and fine root production was estimated using literature data (Neumann *et al*., 2019).

In Latvia, about 18 thousand ha of abandoned cutaway peatlands, where peat extraction has been ceased or completed, but no reclamation has been carried out, are identified within the LIFE REstore project. Afforestation with Scots pine *Pinus sylvestris* L. is one of the best after-use scenarios to maximize climate change mitigation effect. For GHG emission reduction calculation nationally applicable emission factors elaborated in LIFE REstore project (CH_4, CO_2 and N_2O) and default emission factors for temperate moist climate zone according to IPCC 2014 Wetlands supplement (dissolved organic carbon, proportion of ditches and CH_4 from ditches) are used. For peat extraction site afforested with conifers, average net CO_2 emissions are equal to 0.96 t CO_2-C ha^{-1} annually, dissolved organic carbon (DOC) 0.31 t C ha^{-1} annually, CH_4 emissions are 22.39 kg CH_4 ha^{-1} annually, CH_4 emissions from drainage ditches are 217 kg CH_4 ha^{-1} annually and N_2O emissions are -0.05 kg N_2O-N ha^{-1} annually. If peat extraction still continues, net emissions are equal to 1.09 t CO_2-C ha^{-1} annually, DOC 0.31 t C ha^{-1} annually, CH_4 emissions are 10.83 kg CH_4 ha^{-1} annually, CH4 emissions from drainage ditches are 542 kg CH_4 ha^{-1} annually and N_2O emissions are 0.44 kg N_2O-N ha^{-1} annually. In abandoned peat extraction fields that are not covered with vegetation (alternative scenario to compare impact of the afforestation scenario) 0.95 t CO_2-C ha^{-1} annually, DOC 0.31 t C ha^{-1} annually, CH_4 emissions are 1.42 kg CH_4 ha^{-1} annually, CH_4 emissions from drainage ditches are 542 kg CH_4 ha^{-1} and N_2O emissions are 0.11 kg N_2O-N ha^{-1} annually. In abandoned peat extraction fields covered with vegetation that is not a tree stand CO_2 emissions are 1.85 t CO_2-C ha^{-1} annually, DOC 0.31 t C ha^{-1} annually, CH_4 emissions are 28.39 kg CH_4 ha^{-1} annually, CH_4 emissions from drainage ditches are 217 kg CH_4 ha^{-1} and N_2O emissions are 0.04 kg N_2O-N ha^{-1} annually (Priede & Gancone, 2019).

GHG emission reduction potential was estimated by comparison of soil GHG fluxes and carbon stock changes in case of afforestation of the abandoned peatlands and retaining of existing situation (abandoned peatland with poorly developed vegetation). Calculation period is 30 years to demonstrate GHG mitigation potential, which can be reached in 2050 by quick implementation of the afforestation measures in abandoned peatlands.

Results and Discussion

The GHG emission factors according to IPCC 2014 Wetlands supplement and LIFE Restore results applied in the calculation are provided in Figure 1.

In 18 thousand hectares (kha) abandoned peatlands with poorly developed vegetation, GHG emissions from soil according to IPCC 2014 Wetlands Supplement are the following, CO_2 emissions from soil are 171.6 kilotonnes (kt) CO_2 eq. yr^{-1}, DOC 20.5 kt CO_2 eq. yr^{-1}, CH_4 emissions are 1.1 kt CO_2

eq. yr^{-1} and N_2O emissions are 23.6 kt CO_2 eq. yr^{-1}. Total GHG emissions from soil in case of continued abandonment of these areas are 216.8 kt CO_2 eq. yr^{-1}. According to the emission factors elaborated within the scope of the LIFE REstore project CO_2 emissions in 18 kha are 122.1 kt CO_2 eq. yr^{-1}, DOC 20.5 kt CO_2 eq. yr^{-1}, CH_4 emissions are 12.8 kt CO_2 eq. yr^{-1} and N_2O emissions are 0.4 kt CO_2 eq. yr^{-1}. Total GHG emissions from soil are 155.7 kt CO_2 eq. yr^{-1}. Application of country specific GHG emissions factors reduces GHG emissions by 28%.

If 18 kha of abandoned peatlands are afforestated with Scots pine (*Pinus sylvestris* L.) GHG emissions from soil according to IPCC 2014 Wetlands supplement, CO_2 emissions from soil are 171.6 kt CO_2 eq. yr^{-1}, DOC 20.46 kt CO_2 eq. yr^{-1}, CH_4 emissions are 1.09 kt CO_2 eq. yr^{-1}, CH_4 emissions from drainage ditches are 2.44 kt CO_2 eq. yr^{-1} and N_2O emissions are 23.60 kt CO_2 eq. yr^{-1}. Total GHG emissions from soil are 219.19 kt CO_2 eq. yr^{-1}. According to country specific emission factors in 18 thousand ha, CO_2 emissions are 63.5 kt CO_2 eq. yr^{-1}, DOC 20.46 kt CO_2 eq. yr^{-1}, CH_4 emissions are 9.82 kt CO_2 eq. yr^{-1}, CH_4 emissions from drainage ditches are 2.44 kt CO_2 eq. yr^{-1} and N_2O emissions are -0.40 kt CO_2 eq. yr^{-1}. Total GHG emissions from soil if country specific emission factors are applied, reduces to 95.47 kt CO_2 eq. yr^{-1} (by 56%). After afforestation carbon stock in living woody biomass increases to 93 t C ha^{-1}, in dead wood – to 4.50 t C ha^{-1} in 30 years period and in ground biomass – to 2.00 t C ha^{-1} during 5 years period. These values are used in national GHG inventory to determine impact of land use changes.

Reduction of CH_4 emissions from soil following to the afforestation according to IPCC 2014 Wetlands Supplement is 0.02 kt CO_2 eq. yr^{-1} and reduction of CH_4 emissions from drainage ditches -2.44 kt CO_2 eq. yr^{-1}. Total GHG emission reduction from soil after afforestation is negative according to IPCC 2014 Wetlands Supplement -2.41 kt CO_2 eq. yr^{-1}. According to the country specific emission factors, the reduction of CO_2 emissions from soil after afforestation is 58.91 kt CO_2 eq. yr^{-1}, reduction of CH_4 emissions is negative, including -4.9 kt CO_2 eq. yr^{-1} in forest area and -2.44 kt CO_2 eq. yr^{-1} from drainage ditches and reduction of N_2O emissions is 0.77 kt CO_2 eq. yr^{-1}. Total GHG emission reduction from soil after afforestation, if the country specific emission factors are applied, is 60.20 kt CO_2 eq. yr^{-1}. The difference between the default assumptions and country specific method is 14.1 kt CO_2 eq. yr^{-1}. Additional reduction of GHG emissions is ensured by removals of CO_2 in living and dead biomass in forest lands – 9.2 tons CO_2 ha^{-1} yr^{-1}. The net GHG emission reduction does not significantly differ in case of application of the IPCC 2014 Wetlands supplement and country specific emissions factors; in 30 years period it reaches 5000 kt CO_2 eq. (167 kt CO_2 eq yr^{-1}). However, the lack of difference is mainly due to significant contribution of living biomass in the estimation of the GHG emission reduction, which is the same in both scenarios (Figure 2).

In spite of similar values of GHG emission reduction due to afforestation, the absolute values of the emission factors elaborated by the LIFE Restore project team is about twice smaller than the default ones, which means that the GHG emissions from soil in abandoned peatlands and forest lands are significantly overestimated. Emission factors elaborated by the LIFE Restore project have also significantly smaller uncertainty range 30–80% instead of 90%, and they are better adopted to country specific activity data.

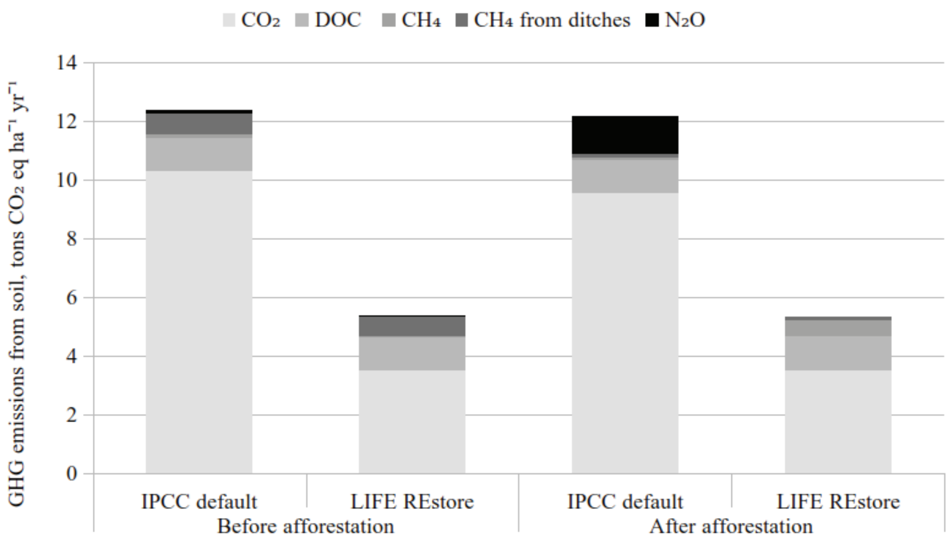

Figure 1. The average annual GHG emissions from soil in afforested area and abandoned peatland.

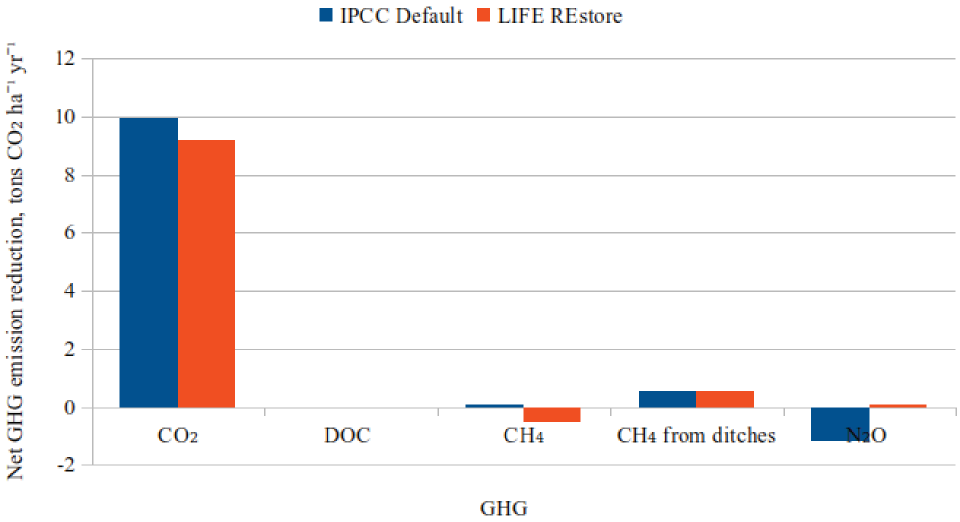

Figure 2. The average annual GHG emission reduction due to afforestation in a 30-year period.

Conclusions

Afforestation of degraded peatlands can contribute to significant GHG reduction in wetlands – up to 20% of the net GHG emissions due to wetlands management. The most of the GHG mitigation potential is ensured by accumulation of CO_2 in living biomass.

Despite the fact that the elaborated emission factors are within the range of uncertainty of the default emission factors provided in the IPCC 2014 Wetlands supplement, application of country specific emission factors is important. They increase accuracy and turn the net increase of GHG emissions from soil due to afforestation, if the default emission factors by the Wetlands supplement are applied, into net removals, if the country specific factors are applied.

Increase of accuracy of the emission factors is also important, because the value and sign of different GHGs is changing – CH_4 turns into net source of emissions and value of N_2O and CO_2 reduces, which points to the conclusion that the default emission factors reflect different conditions (water regime, soil fertility) in comparison to Latvia.

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