Brief Report

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Hands-On Approach to Foster Paludiculture Implementation and Carbon Certification on Extracted Peatland in Latvia

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Abstract: Voluntary carbon markets open horizons for private companies, public institutions, and individuals developing CO_2 removal projects in peatlands to reduce overall carbon footprint. These steps, however, should be in line with appropriate rewetting targets. To do so, the base line information about the status of area must be assessed. Here we follow the methodology set by the carbon certification program standards which define the necessary steps for reference conditions assessment. In this study we practically test the fulfilment of necessary drained peatland baseline evaluation for paludiculture and carbon certification activities. Estimates on the greenhouse gas emission mitigation potential were summarized to define priorities and propose quantifiable measures with suggested paludiculture implementation. Our hands-on approach shows that it is possible for companies to implement rewetting strategies without large EU level project fundings when the conservation and economic aspects are met, thus boosting climate mitigation actions.

Keywords: peat; CO_2; CH_4; rewetting; GEST; hydrogeology; photogrammetry

1. Introduction

Climate warming and human impacts are thought to be causing peatlands to dry, converting them from sinks to sources of carbon [1]. Countries are encouraged to include peatland conservation, protection, and restoration in their commitment to international climate agreements [2,3]. Challenge is to design sustainable land use, including ecologically sound yet economically viable strategies to conserve biological diversity, carbon storage capacity and other ecosystem services. Latest initiatives aim to support and scale up the rewetting of drained peatlands as an effective climate mitigation solution, by helping to establish peatlands carbon offset programs and schemes [4]. Rewetting organic/peat soils and peatland areas ensures natural, climate and economic-friendly usage of these areas through paludiculture (agriculture and forestry on wet and rewetted organic/peat soils and peatlands). Paludiculture is recognized as one of the nature-based solution tools in climate and biodiversity crises mitigation. This approach includes a significant carbon sequestration and long-term storage which enhances the resilience of carbon stock, thus cooling the climate. Peatland ability to sequester carbon is being considered in the national GHG emission assessments and private initiatives as a potential source of revenue to manage carbon-balanced landscapes and pay for ecosystem services [5–7].

According to the voluntary carbon market protocols, private companies, public institutions, and individuals can develop CO_2 removal projects, transect carbon credits generated and reduce their overall carbon footprint. While the European Commission published its legal proposal for the Carbon Removal Certification Framework, aiming at establishing a governance and criteria for quantification, additionality and baselines, long-term storage, and sustainability, there is a lack of

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binding legislation framework at the national levels of EU [8]. For example, the Latvia's national energy and climate plan for the 2021–2030 propose to focus on afforestation as the main action for decreasing GHG emissions (including afforestation of peat and organic soils) and not mentioning nor voluntary carbon markets nor indicating possible carbon certification framework establishment [9]. Indeed, it is surprising because nearly 12% of the territory of Latvia is covered by peatlands of which considerable share (~39500 ha) are so-called degraded and needs to be revitalized. At this very moment, all three Baltic countries (Lithuania, Latvia, and Estonia) are one of the largest GHGs emitters (>50 MT CO_2 e annually) from degraded peatlands within the EU [10] and there are available voluntary carbon schemes and rewetting and paludiculture possibilities to choose from [11–13].

To be able to implement these nature-based solutions through reclamation and recultivation initiatives widely, some critical aspects of extracted peatlands must be considered: (1) is it realistic for individual enterprises to run peatland restoration without a large funding support (e.g., EU LIFE, HORIZON2020 etc. project funding resources)?; (2) what baseline information is necessary to obtain for successful rewetting, paludiculture and carbon certification?

The aim of current study was to practically test the fulfilment of necessary peatland baseline evaluation for paludiculture and carbon certification activities. For this we selected unused (at least for the last two years) extracted peatland area (16.4 ha) within the active peat extraction field in Latvia, North-Eastern Europe (Figure 1). Here we intentionally aimed to outreach a company working in peat extraction field. We choose an active company because to rewet peatlands as soon as possible, one should do these recultivation activities from bottom-up approach, i.e., from the landowners and managers to the national scale. The other aspect was to see how realistic it is to get the private enterprise credibility and trust for nature-based climate mitigation solutions in the Latvia where peat extraction companies in general are skeptical about the implementation of paludiculture and rewetting. That said, through this study, other enterprises will see that it is feasible and how all steps can be aligned with their own budget lines, i.e., not waiting for large project fundings and start acting Today.

2. Materials and Methods

Although implementation of paludiculture, rewetting and carbon certification sounds like different activities, they all comprise similar principles regarding field and setting requirements [13–15]. Hence, here, we followed guidance set by the Verified Carbon Standard (VCS; VERRA VM0036 methodology; the most widely used standard for land use projects [16]) and the MoorFutures® (Germany scheme that has set the standard in Europe [17]). Both standards use the Greenhouse Gas Emission Site Type (GEST) approach for quantification of greenhouse gas (GHG) emission reduction from rewetted drained peatlands in temperate climatic regions. Due to experimental nature, we outreach "Laflora" Ltd peat extraction company which is open for such *science-to-practice* activities (e.g. [18,19]) and made an agreement between Lake and Peatland Research Centre to run project "*Vegetation and water monitoring for paludiculture and carbon sequestration projects at "Laflora" Ltd*". Importantly, company had no influence on any conclusions or work related to this seven-month project (lasted from April to November 2023).

For rewetting and carbon certification purposes it is necessary to set the baseline setting which then will serve as the reference conditions for further implementation activities. We had opportunity to work on 16.4 ha large abandoned extracted peatland within the active peat extraction license field (Figure 1.). The area, Kaigu (Veļu) bog is located in Līvbērze county (17 km to the closest city Jelgava with population of ~56,000 people). The total area of Kaigu bog is 1,546 ha and the peat extraction takes place on 774 ha. According to the natural resources mining license and reserves of suitable peat in Kaigu bog, company could extract peat at least for the next ~80 years.

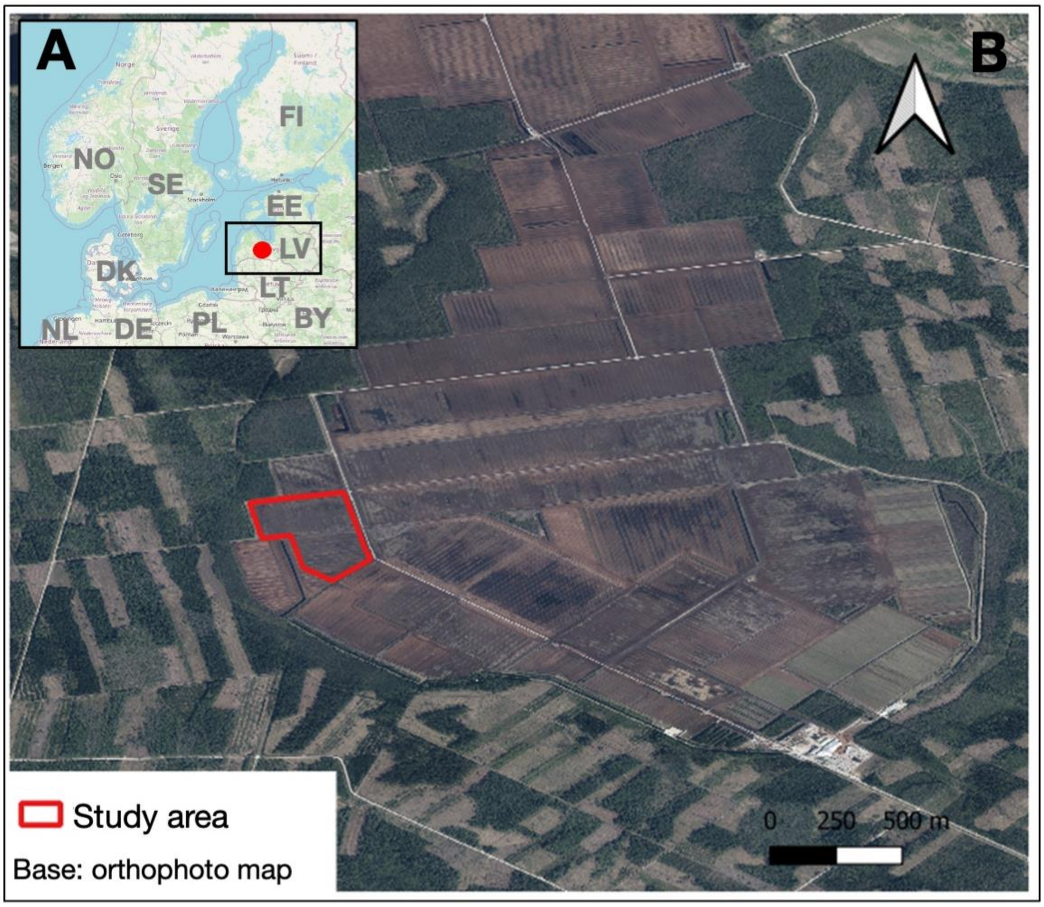

Figure 1. Location of Latvia in North-Eastern Europe (A) and study area - extracted peatland area (B).

Methodologically we defined working-packages where we:

(1) explored peat thickness (geological coring within 100x100 m frame and following interpolation in QGIS) and its characteristics (botanical type, pH and decomposition rate [20], relative composition (loss-on-ignition [21]) and carbon stock [22] analyses with a summary statistics (PAST software [23]) for nine samples and upscaled estimates for the whole area);
(2) run water monitoring (six ground water monitoring wells equipped with TD-Diver (*vanEssen Instruments*) groundwater level loggers);
(3) sampled groundwater and surface water for chemical (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, Cl^-, N_{total}, NH_4^+, N-NH_4^+, N-NO_2^-, N-NO_3^-, P_{total}, PO_4^{3-}) analyses in the accredited laboratory and onsite properties using express tests (pH, electric conductivity, alkalinity, iron concentration; Dist3 and pHep+, HI775, HI96721 *Hanna Instruments*);
(4) inspected vegetation and landcover (GEST methodology [24,25]);
(5) applied photogrammetry (with DJI Phantom RTK drone, 8.8 mm FC6310R camera 5472x3648, resolution for pixel 2.41x2.41 μm; five ground control points tied with GPS *Emlid RS2+ RTK GNSS*) to get high-resolution landcover and digital elevation model maps (using *Agisoft Metashape Professional* software and QGIS) for landcover zonation;
(6) estimated GHG based on GEST [25];
(7) made 2D groundwater flow models (QGIS, *thinPlateSpline* interpolation method on observed water levels + boundary conditions using Lidar data) to understand water dynamics;
(8) proposed further steps according to the results.

3. Results

Most time-consuming work was related to the groundwater monitoring and water flow modelling (lasted from April to November 2023). Survey of geological setting and analyses were done

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within three month (April to June 2023). Vegetation was investigated during the vegetation season, at the same time when the photogrammetry was carried out (August 2023). GHG estimated after GEST method during October and November 2023).

Following the requirements for baseline scenario set by the carbon certification standards, we achieved all the necessary indices for further recultivation activities. Through the geological survey which was basically an assessment of the leftover peat and the carbon stock it holds, we found that the 16.4 ha area have 151,700 m³ peat reserves (85,690 m³ raised bog peat; 66,010 m³ fen type peat). Thinnest peat thickness was 0.3 m and the largest thickness of peat layer was 2.8 m (Figure 2A). When considering the average carbon concentration for the raised bog peat 554.5 g C/m² (with peat density 113.36 kg/m³; n=3) and fen type peat 801 g C/m² (with peat density 169.46 kg/m³; n=6), the total carbon stock in the remining peat is estimated as high as 14,347.04 t C. When to convert to CO_2 emissions, this means that left peat reserves are holding potential of 52,653.64 t CO_2 emissions.

According to the landcover and vegetation communities, six GEST types were identified within the 16.4 ha (Figure 2B, C): (1) GEST 5 (Bare peat dry (OL) 2.15 ha, (2) GEST 6 (Bare peat moist (OL) 2.77 ha, (3) GEST 8 (Very moist meadows, forbs and small sedges) 0.03 ha, (4) GEST 13 (Wet tall sedges reeds) 3.76 ha, (5) GEST 15 (Wet tall reeds) 6.62 ha, and (6) GEST 20 (open water/ditches) 1.07 ha. The total emissions (following GEST emission factors established by [25]) from 16.4 ha are as high as 165.502 t CO_{2eqv}/year (CO_2 = 60.168 t CO_2/year; CH_4 = 105.334 t CO_{2eqv}/year).

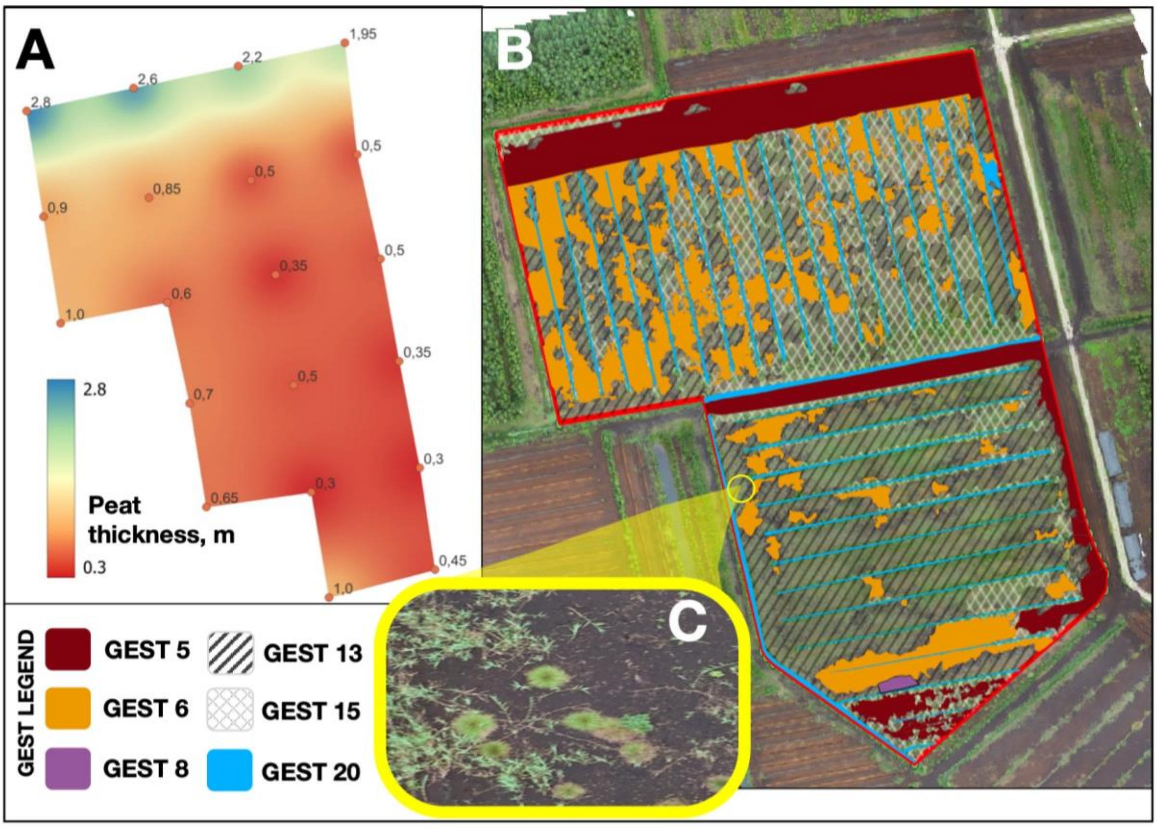

Figure 2. General information on land unit: A – peat thickness map (interpolation based on raw coring data), B – land-use according to the defined Greenhouse Gas Emission Site Types. C – photogrammetry map resolution example with a closeup to show the detail of obtained orthophoto map.

Electric conductivity measurements reveal values (μS/cm) 150 for a ditch water and ranged from 388 to 866 (average 746.4) in groundwater. The pH in a ditch was 6.53 and range from 6.71 to 7.19 (average 6.908) in groundwater. Alkalinity (ppm) for a ditch water was 34, but for groundwater from 192 to even >500 (above the maximum detection limit). Total iron concentration (mg/l) in a ditch water

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was 2.22, and in three out of five groundwater samples showed 2.41, >5 (above the maximal detection limit) and 4.1. Groundwater is dominated by calcium and magnesium cations and bicarbonate anions, while ditch water is also dominated by bicarbonate anions, but its concentration is 11 times lower than in groundwater. Groundwater sample contains 1.85 mg/l total nitrogen which is primarily in the form of ammonium ions (1.68 mg/l N-NH_4^+), indicating relatively high nutrient presence, whereas ditch water sample contains much lower concentrations (0.28 mg/l N-NH_4^+). The phosphorus concentration in groundwater was below detection limit and at the detection limit in surface ditch water (0.006 mg/l).

Significant changes in the groundwater system and water flow directions have been observed throughout the observation period (Figure 3). In June and July, a decrease in groundwater levels was mainly due to evapotranspiration, as observed by the diurnal variations in groundwater levels. The groundwater flow distribution for the beginning of June shows that the groundwater is flowing towards the drainage ditches. The highest absolute levels occur in the vicinity of core No.5 (urb5), which is defined by the natural peatland remain to the west of it, which is characterized by a hypsometrically higher relief (Figure 3). Late July is characterized by the lowest groundwater levels of the whole observation period, due to the hot summer and intense evapotranspiration (both from the ground/water surface and transpiration through plants). The lowest groundwater levels were observed in well No.3 (urb3) with a drop of groundwater level to just 0.49 m asl. or 2.34 m below the surface, while the water level in ditch was higher (1.42 m asl.). At the end of October, groundwater levels recovered because of autumn rainfall and also groundwater flow routes recovered with the main flow direction towards the ditches. Over the observed period the water table in the central part of the southern study field changed significantly with relative groundwater level variations up to 1.83 m, while northern field showed more stable groundwater level conditions (still groundwater level changes up to 0.79 m though).

During reporting of the results, continuous bilateral communication with the company was done to aid additional explanation to the reports for each working package. For future reference, one should allocate additional working hours for communication as such projects are not self-explanatory for the companies. Before one can proceed with the actual implementation of rewetting or paludiculture practices, it is important to see the reference conditions. Our results and gained experience with the current project show that at least half a year is necessary to obtain basic information for paludiculture and carbon certification projects. Total costs to estimate peatland baseline conditions for paludiculture and/or carbon certification activities can range from 1300 to 4000 EUR/ha (depending on the complexity of site and wage for experts). This does not include further modelling and possible implementation projects.

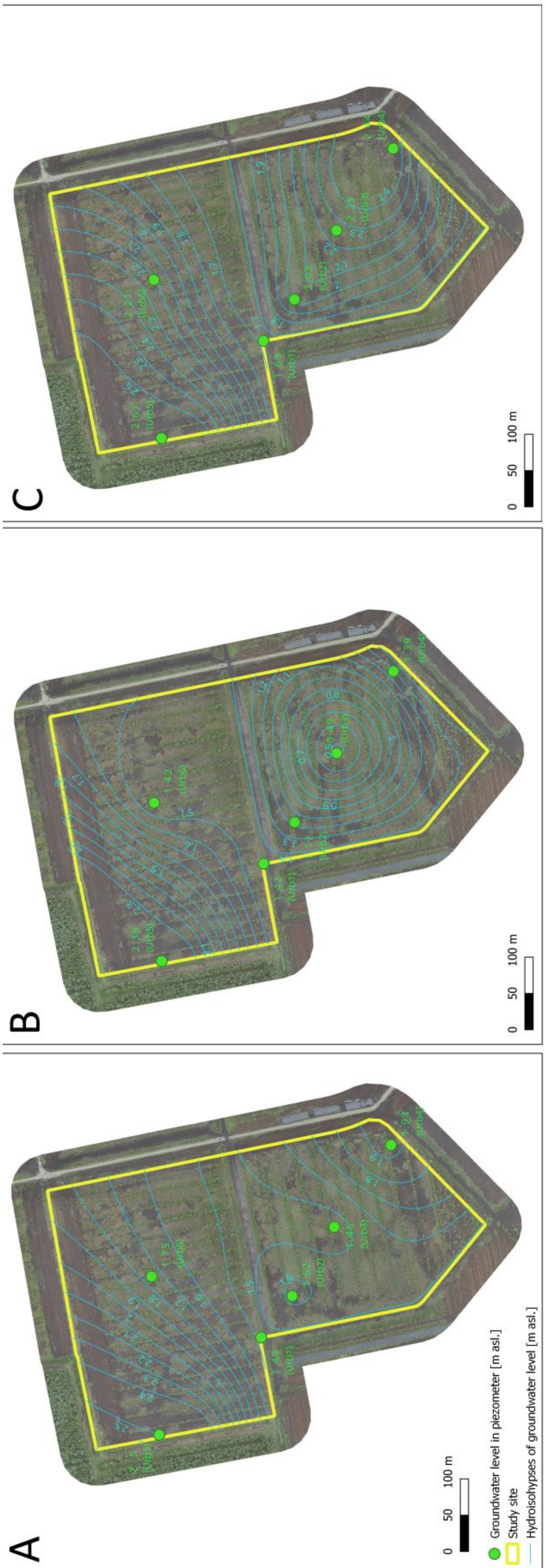

Figure 3. Groundwater flow models for A – early spring, B – summer, and C – autumn.

4. Discussion

Our results indicate unexpected groundwater chemistry and properties for a particular peatland setting where alkaline and nutrient rich waters are below the thin peat layer. These groundwaters eventually will define further success for implementation of paludiculture due to their location near to the surface. In our study site groundwater table fluctuates even up to 1.83 m and it has been showed that under such conditions more GHG are emitted [26–28]. Hence, highly variable groundwater levels aid to need for recultivation actions which require a thoughtful planning to ensure necessary hydrological conditions, i.e. stable water level close to the peat surface (10-30 cm from the surface). Extracted field maintenance (surface levelling, ditch enclosure) with the aim to obtain constant hydrological conditions should be planned for successful paludiculture implementation and GHG with low global warming potential [29,30]. At the same time, one should be aware that by doing so, novel peatland ecosystems are established which cannot be directly assumed as natural sites [31].

Based on the results (groundwater chemistry, water level, peat type and thickness) several paludiculture taxa options are possible in particular circumstances: reed (*Phragmites australis*), reed canary grass (*Phalaris arundinaceae*), cattail (*Typha angustifolia/latifolia*) or sedges/wet meadow [11]. Because the water level in the northern part of the area (9.016 ha) has lower fluctuations and can be managed to keep closer to the peat surface (Figure 3), wet sedges [29] could be grown capturing 54.1 t CO_2 annually. In the southern part area (7.384 ha) reed canary grass can be as possible option for paludiculture. Reed canary grass [24,27] could capture in total 26.213 t CO_2 annually. Even higher benefit can be gained with common reed reaching 66.01 t of CO_2 captured annually. Other possible scenarios can be considered from both biodiversity and greenhouse gas (GHG) perspective (e.g., [11,33]). Rewetting and paludiculture thus would omit current 60.17 t CO_2 annual emissions and capture additionally 80.31–120.11 t CO_2 per year (total benefit omitted 140.48–180.28 t of CO_2 annually from 16,4 ha drained peatland).

Large emissions mean also significant mitigation potential. Therefore, available estimates on the GHG mitigation potential were summarized to define future priorities and propose quantifiable measures under paludiculture implementation (both climate and economical profit). By implementing recultivation measures in this area, there's a significant opportunity to enhance its function as a carbon sink. Recultivation in this context can lead to several beneficial outcomes. First of all, the retention of existing carbon stored in peat which by our estimates comprise 14,347.04 t C. If drainage will continue, then it poses a risk of releasing stored carbon into the atmosphere contributing 52,653.64 t CO_2 to the GHG. Secondly, aboveground biomass of reed canary grass if harvested could bring 7.9–13.2 t ha^{-1} that can be used for pellet production [19]. Usage of aboveground biomass is crucial to meet the overall climate benefits as it has been showed by the life cycle assessment for paludiculture practice [34].

Latvian peatland extracting companies are bind by a given mining license which mandates after peat extraction to recultivate peatland either to waterbody, afforestation or revitalization back to natural peatland status. Hence, in such cases, no additionality applies, and no carbon credits can be generated. Only the projects of peatland recultivation where there is no legal obligation to restore peatland as natural bog ecosystem (e.g., defined by the license or the site is abandoned degraded peatland) might be an option. According to the natural resource mining license, particular peat company could extract peat in current area (next to the studied area) at least for the next ~80 years. Only after a complete extraction full recultivation theoretically could take place. Given that the company is ready for rewetting ~80 years earlier than required by the lease and legislation, the additionality principle could apply. Without rewetting actions, GHG emissions from exposed and drained fields will be released over the next ~80 years and the remaining peat will mineralize and decompose.

All ongoing activities with the aim to generate carbon units are welcome from climate mitigation point of view. However, unclear aspects are related to carbon double counting, lack of clarity about the organic soils and LULUCF at the national level. European Union is setting the stage for carbon certification framework which most likely will include principles of Taxonomy (EU taxonomy). Until

Latvia will develop its own carbon certification schemes, all the actions related to rewetting and paludiculture for offsetting, insetting and carbon certification projects shall follow the existing voluntary carbon market standards and upcoming EU regulations.

Our hands-on approach shows that it is possible for companies to implement rewetting strategies without large EU level project fundings when the conservation and economic aspects are met. Assessment of the baseline conditions setting a stage for the bog recultivation, thus representing a proactive approach to both preserving existing carbon stores and enhancing future carbon sequestration. This dual strategy is an effective way to combat climate change and contributes positively to global efforts in reducing atmospheric CO_2 levels.

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Data Availability Statement: Data is available upon the request from the main (corresponding) author.

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