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Under which conditions is it still Green Energy? Photovoltaics on organic soils: A scenario analysis for Germany

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Abstract

Solar parks generate emission-free electricity, but installations on drained organic soils can lock in substantial greenhouse gas (GHG) emissions from peat oxidation. Therefore, combining ground-mounted photovoltaics (GM-PV) with rewetting is emerging as a multifunctional climate mitigation strategy in temperate peatland regions. Despite growing interest, data on GM-PV on organic soils (Peatland-PV) remain limited. To address this gap, we conducted a geospatial analysis of Germany's Peatland-PV plants, quantifying associated water table depths (WTD) and GHG fluxes. Based on these findings and socioeconomic projections from the literature reflecting different policy frameworks, we developed three exploratory scenarios of future expansion under three rewetting regimes each. Peatland-PV solar panels covered 1,019 ha of organic soils in Germany as of 1 January 2026 and could expand to 2,604–8,031 ha by 2045 according to our model. We found that most existing sites are deeply drained (median WTD ca. −0.5 m), resulting in annual soil emissions of 39 kilotons (kt) CO_2-eq from the panel–soil intersection area. The future GHG balance of the Peatland-PV sector depends on expansion rate and rewetting policy, rather than geographic location. Continued drainage of Peatland-PV plants could sustain nationwide organic soil related GHG emissions of 89–274 kt CO_2-eq yr^{-1} by 2045, while rewetting may reduce these emissions by 21–49%. Our scenarios indicate that Peatland-PV may initially contribute to net climate cooling mainly due to avoided fossil emissions, but under continued drainage a crossover point could occur 2039, at which soil emissions exceed mitigation benefits from renewable energy production.

Keywords: Peatlands, Rewetting, Peatland-PV, Photovoltaics, LULUCF, Climate mitigation

Abbreviations

BauGB	German Federal Building Code (Baugesetzbuch)
BNetzA	Federal Network Agency (Bundesnetzagentur)
DOC	Dissolved organic carbon
DP-PV	Drained peatland photovoltaics
EEG	Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz)
GHG	Greenhouse gas
GM-PV	Ground-mounted photovoltaics
GWP	Global warming potential
GWp	Gigawatt-peak
IPCC	Intergovernmental Panel on Climate Change
KSG	Federal Climate Protection Act (Bundes-Klimaschutzgesetz)
LULUCF	Land use, land-use change, and forestry
MaStR	Core energy market register (Marktstammdatenregister)
MWp	Megawatt-peak
NIR	National Inventory Report

PALU-RL	Paludiculture funding directive (Paludikultur-Richtlinie)
PD	Power density
PPA	Power purchase agreement
PV	Photovoltaics
REMod	Regenerative Energy Model
RP-PV	Rewetted peatland ground-mounted photovoltaics
UNFCCC	United Nations Framework Convention on Climate Change
WTD	Water table depth

1. Introduction

More than 150 countries have announced or are considering climate neutrality targets (Zhang et al. 2025). Some have set specific target years, e.g., China by 2060 (Liu et al. 2021) or Canada (Boluwade 2025) and the EU by 2050 (Kougias et al. 2021), or even earlier dates, such as Finland by 2035 (Laasasenaho et al. 2023). Germany has set its target year to 2045, as mandated by the Federal Climate Protection Act (KSG). This requires both energy demand reduction and a major expansion of renewable energy, with ground-mounted photovoltaics (GM-PVs) serving as a central transformation component (Süsser et al. 2021; Thelen et al. 2024; Wiese et al. 2022). However, climate neutrality cannot be achieved through the transformation of the energy system alone, as substantial greenhouse gas (GHG) emissions also originate from land use and land-use change (UBA 2026).

In the context of land use, peatlands play a critical role. These wetland ecosystems are characterized by the accumulation of partially decomposed organic matter, resulting in the formation of peat (Milner et al. 2026). Germany contains 1.9 million ha of organic soils, which are or have been peatland soils, storing massive amounts of carbon accumulated over centuries under waterlogged conditions (Wittnebel et al. 2023). However, the vast majority of these organic soils have been drained, primarily for agricultural use (Martens et al. 2026; Tiemeyer et al. 2020). Drainage exposes stored carbon to aerobic conditions and accelerates microbial peat oxidation (De Jong et al. 2021; Leifeld et al. 2025), transforming former net carbon sinks into ‘GHG hotspots’ (Bockermann et al. 2024). As a result, drained organic soils make a disproportionate contribution to GHG emissions and are a major challenge for the transformation of the land use, land-use change and forestry sector (LULUCF) from a net source into a net sink (UBA 2026).

This transformation is essential for achieving Germany’s climate targets. While the LULUCF sector currently emits more GHGs than it removes (UBA 2026), the German Climate Change Act (KSG) requires the sector to become a substantial net carbon sink, with average net removals of 25 Mt CO_2-eq yr^{-1} in 2027–2030, 35 Mt CO_2-eq yr^{-1} in 2037–2040, and 40 Mt CO_2-eq yr^{-1} in 2042–2045 (§3a KSG). Therefore, achieving these targets requires substantially reducing emissions from drained organic soils. Rewetting is the most effective measure to

reduce emissions driven by decomposition processes (Tiemeyer et al. 2020; Wilson et al. 2015) and provides other environmental benefits (Leifeld et al. 2025; Martens et al. 2026). However, despite the urgent need to reduce GHG emissions, it is unlikely that all drained organic soils can be restored to natural wet wilderness in time to meet international net-zero commitments, as they remain under substantial agricultural and economic pressure (Evans et al. 2021).

Combining peatland rewetting with photovoltaic (PV) electricity generation is increasingly discussed as a promising dual climate mitigation strategy that can stabilize organic soil carbon stocks while enabling renewable energy production and generating economic returns (Belzons Berthelemot et al. 2026; Fakharizadehshirazi and Rösch 2024; Seidel et al. 2024). Since 2023, solar parks constructed on drained organic soils previously used for agriculture have been financially supported under Germany's Renewable Energy Sources Act (EEG) through a feed-in tariff bonus of 0.005 EUR kWh^{-1} compared with conventional GM-PV systems, provided that permanent rewetting is implemented. Within the funding scheme, rewetting is defined as a water table depth (WTD) of -30 cm in summer and -10 cm in winter. However, new GM-PV plants on organic soils without rewetting remain legally permissible outside the EEG support scheme (e.g., through power purchase agreements, PPAs), thereby locking in elevated GHG emissions from drained organic soils for decades. To distinguish between these two management approaches, we classify Peatland-PV, defined as all GM-PV plants intersecting with organic soils, into Rewetted Peatland-PV (RP-PV) and Drained Peatland-PV (DP-PV).

Given the relevance of this topic to both the energy transition sector and the LULUCF sector, it is surprising that peer-reviewed research on Peatland-PV remains scarce and, to the best of our knowledge, is currently limited to a small number of papers (Martens et al. 2026; Schwill et al. 2025; Seidel et al. 2024). Our study therefore aims to broaden the scientific perspective on this emerging climate mitigation technology by applying geospatial analysis — an established approach for assessing land-use patterns of GM-PVs (Belzons Berthelemot et al. 2026; Fakharizadehshirazi and Rösch 2024) — to provide an evidence base for strategic decision-making. First, we determine the current status quo by quantifying the existing deployment of Peatland-PV systems and the associated WTD and soil GHG emissions in Germany. Second, we developed three exploratory deployment scenarios to assess how future land consumption and GHG balances may evolve under different rewetting policy frameworks, accounting for both organic soil GHG fluxes and avoided emissions from electricity generation. Considering current political frameworks in Germany, our findings illustrate the range of potential GHG emission outcomes associated with the Peatland-PV segment, thereby highlighting both the opportunities and the risks of this emerging technology. These insights

may help to provide an empirical basis for refining regulatory frameworks in temperate peatland countries to effectively guide future Peatland-PV deployment.

2. Methods

2.1 Geodata and status quo analysis

The geospatial analysis of German GM-PV plants on organic soils was conducted via Python (GeoPandas, version 0.9.0) and QGIS 3.40.4 (Bratislava). Large Language Models, specifically OpenAI's ChatGPT and Google's Gemini, were employed to support the optimization of the data processing codes in Python, whereby all AI-generated suggestions were manually verified, integrated and tested by the authors. To derive the current characteristics of GM-PV plants in Germany, the dataset from Manske (2026), which, to our knowledge, is the most comprehensive geospatial dataset of renewable energy plants in Germany, was used. It is based on onsite verified data exports from the core energy market register (MaStR) by the Federal Network Agency (BNetzA), providing module-level outlines of GM-PV plants alongside relevant technical attributes. The power density (PD), defined as the ratio of installed capacity to the GM-PV modules per hectare, was calculated as the annual median for all GM-PV plants. For 396 of the 14238 polygons, no technical information was available. For these, the global PD was used, and commissioning years were set randomly, proportional to the known commissioning rates per year.

To analyze the coverage and properties of organic soils (peat and other organic soils) under Peatland-PV plants, the updated map of organic soils in Germany by Wittnebel et al. (2023) was used. This dataset represents the most up-to-date, nationwide map of organic soils in Germany and was compiled from peat and soil maps provided by the responsible state authorities. The organic soil map was spatially intersected with the GM-PV dataset via the *GeoPandas overlay* function to characterize the site conditions beneath the modules. Each resulting intersection area was attributed with specific soil parameters from the organic soil map, including peatland genesis (fens vs. bogs), soil stratigraphy (mineral cover layers), peat thickness (ranging from peaty topsoils to deep peat layers > 2 m), deep plowing, limnic sediments (presence of mud), and the composition of the underlying mineral substrate.

To determine the current WTD and GHG emissions of organic soils under Peatland-PV plants, we used the LULUCF dataset from the German National Inventory Report (NIR) under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement (UBA, 2026). The dataset includes soil CO_2, CH_4 and N_2O emissions, as well as CO_2 derived from dissolved organic carbon (DOC) mineralization. Following the NIR, all soil emissions are expressed as CO_2 equivalents (CO_2-eq) to ensure standardized comparability,

using Global Warming Potentials (GWPs) of 28 for CH_4 and 265 for N_2O, as specified from the International Panel of Climate Change (IPCC) guidelines and likewise applied by Bechthold et al. (2014), Frank et al. (2025) and Tiemeyer et al. (2020). The dataset was provided as a point-based vector grid with a spatial resolution of 100 m × 100 m. Its GHG and WTD components utilize 2020 climate data, ensuring consistency with the suitability map described below.

We included the suitability map for RP-PVs derived in the RoVer project (RessortForschtKlima 2025). This dataset integrates soil suitability for PV installation, land-use planning and legal constraints, as well as the general suitability of drained peatlands for rewetting. Suitability is represented on a 100 m × 100 m vector grid covering Germany's organic soils and is expressed as a score ranging from 0 (excluding area) to 10 (highest suitability). The emission dataset (UBA 2026), containing point-specific information on WTD, GHG, and land use, was integrated with the PV suitability data and then clipped to a 2 km buffer around all identified Peatland-PV plants to reduce the computational load. Afterwards, the nearest emission point was assigned for each Peatland-PV plant. When multiple fitting points were present, the arithmetic mean was calculated. The distances from the depicted point to the polygon edge are used. If the nearest neighbor was farther than 100 m from an intersection area, overall median values for WTD and soil GHG emissions were assigned, while land-use information was excluded to prevent potential bias. The land use information originates from the Authoritative Topographic-Cartographic Information Systems - Digital Basic Landscape Model (ATKIS®-Basic DLM). Only points classified as unutilized land ('wetland', Tiemeyer 2020), grassland, or cropland were considered for assignment to Peatland-PV sites.

Since organic soil deposits are naturally heterogeneous and often map as complex, noncontiguous polygons, a single Peatland-PV plant frequently spans multiple distinct organic soil patches or varies between peat and mineral soils within its boundaries. Consequently, the initial geospatial intersection splits the coherent facility geometry into multiple disjoint polygon snippets sharing the same unique identifier (MaStR-IDs). To resolve this, we applied a postprocessing aggregation step to aggregate those snippets into complete Peatland-PV solar parks. Here, all individual intersection areas sharing the same MaStR-ID were grouped, and their geometries were combined. The corresponding WTD and soil GHG values were averaged by their means to assign a single representative value per aggregated Peatland-PV solar park.

2.2 Scenarios for future deployment of GM-PVs on organic soils

The future expansion of Peatland-PVs (in our study from 1 January 2026 onward) is difficult to predict, as it depends on a complex interplay of economic, political, technological, and societal factors. Accordingly, as in any scenario-based study, assumptions and constraints must be

defined (Wiese et al. 2022). To capture a wide range of potential future trajectories, we developed three internally consistent narrative scenarios: Boost (a), Balance (b), and Brake (c). These scenarios were designed to provide a wide range of plausible future developments and can be described as follows:

a) Boost represents an ambitious future characterized by high transformative readiness and rapid technological adoption,
b) Balance serves as a moderate trajectory with a robust transformation pace,
c) Brake assumes stagnant growth and social resistance, leading to slow technology adaptation

The derivations of the scenario parameters and their target values are described below and summarized in Table 1.

2.2.1 Determining scenario-based deployment ratios

Scenario foundations were derived from the Regenerative Energy Model (REMod) projections in the study of Thelen et al. (2024), which provides disaggregated figures for Germany's GM-PV deployment until 2045. We adopted three of their four GM-PV deployment scenarios (*Effizienz* for Boost, *Robust* for Balance and *Beharrung* for Brake), which represent the maximum spread of socioeconomic and political framework conditions.

To determine the baseline share of installed GM-PV plants on organic soils (Peatland-PV) compared with those on mineral soils, we used the current organic soil coverage fraction of 2.7%, which was determined according to the methodology detailed in Section 2.1. This baseline share was linearly interpolated annually toward scenario-specific 2045 target shares, reflecting each scenario's assumptions, and subsequently applied to the respective REMod GM-PV deployment projections. The resulting installed capacities and area consumption of Peatland-PV plants in 2045 are part of the final model outcomes.

2.2.2 Technical assumptions of power density and full-load hours

Annual capacity growth was converted into land-take requirements via time-dependent PD assumptions. Again, the baseline value was adopted from our status quo data on Peatland-PV. We prioritized this data-driven value over frequently cited assumptions for Peatland-PVs below 1.0 MWp ha^{-1} (Keinath et al. 2026; Wirth 2026), as these assumptions currently lack empirical validation (Schwill et al. 2025). The baseline value of 1.25 MWp ha^{-1} was linearly interpolated toward the scenario-specific targets in 2045, as shown in Table 1. A national

average of 950 full-load hours was applied across all the scenarios, aligned with the assumptions of the German transmission system operators and the BNetzA (BNetzA 2025).

2.2.3 Electricity mix and emission accounting

The avoided electricity GHG emissions were calculated by comparing the Peatland-PV-generated electricity with the projected carbon footprint of the German electricity mix. Following UNFCCC territorial accounting, PV-generated electricity is treated as emission-free for Germany (UBA 2026). To account for the historical carbon footprint of Germany's electricity, the factors reported by Icha and Lauf (2026) were applied. Each deployment scenario was paired with an emission factor study representing a corresponding decarbonization pathway: rapid decarbonization for Boost based on Luderer et al. (2025), moderate decarbonization for Balance based on Thelen et al. (2024), and very slow decarbonization based on UBA (2025) for Brake (Table 1).

Tab. 1 Scenario specifications for Boost (a), Balance (b), and Brake (c) at the 2045 model horizon.

Scenario parameter	Boost	Balance	Brake
National GM-PV capacity [GWp]	160.0	150.4	100.0
Organic soil coverage fraction [%]	15.0	5.4	2.7
National electricity footprint [g CO_2-eq kWh^{-1}]	0.0	11.0	42.3
Annual full load hours for Peatland-PV [h]	950	950	950
Power density for Peatland-PV [MWp ha^{-1}]	1.5	1.25	1.0

2.3 Implementing rewetting pathways and time-for-space simulation

In addition to the expansion scenarios and electricity generation for Peatland-PV systems as a subsegment of GM-PV systems in general, the GHG emissions from the affected organic soils are highly relevant. To quantify the future GHG trajectories of those organic soils, we implemented a space-for-time substitution approach by simulating three distinct rewetting pathways for each deployment scenario, thereby representing alternative management strategies for all future Peatland-PV plants. These rewetting pathways are defined as follows:

- Drained: represents a baseline where future Peatland-PV plants are not accompanied by any rewetting measures (DP-PV)
- EEG-compliant: aligns with current legal requirements for RP-PV of the EEG by targeting a seasonal WTD of -10 cm in winter and -30 cm in summer, represented here as a simplified annual mean WTD of -20 cm for simulation purposes

- Ambitious: A more ambitious RP-PV policy framework mandating an elevated annual mean WTD of -10 cm, which closely approaches the ideal conditions for peatland rewetting (Evans et al. 2021; Leifeld et al. 2025; Tiemeyer et al. 2020)

Measurements of soil parameters and ecological impacts below GM-PV plants are rare (Seidel et al. 2024). Specifically, for Peatland-PV systems, empirical GHG flux measurements are currently unavailable (Schwill et al. 2025). To overcome this lack, we adopted GHG fluxes from established land use categories on organic soils within the emission dataset of the UBA (2026), assuming that coverage with GM-PV modules has a negligible effect on soil emissions compared with the main drivers: WTD and vegetation.

To locate future Peatland-PV plants, the aforementioned suitability map for RP-PVs (Chapter 2.1) of the RoVer-Project (RessortForschtKlima 2025) was used. Only sites with a suitability score in the upper half (≥ 5) were included. This prefiltering step ensures that our simulation reflects mainly sites where deployment is practically and legally most realistic. The filter reduced the included organic soil area of Wittnebel et al. (2023) from 1.9 million ha to 1.2 million ha. From this refined dataset, three distinct sub-datapools were constructed, each consisting only of data points that met the specific land use and WTD requirements of the respective rewetting pathway (Drained, EEG-compliant, Ambitious). This approach allows for a differentiated simulation of GHG mitigation potential on the basis of the unique baseline conditions of each pool.

Consistent with Schwill et al. (2025), grassland was identified as the most appropriate proxy land use for Peatland-PV. Accordingly, all the grassland points were included as baselines of the sub-datapools from the Drained, EEG-compliant and Ambitious rewetting pathways. The precondition was that these points also match the respective WTD thresholds of the pathways, which were <−20 cm for Drained, -20 cm ± 2 cm for EEG-compliant and -10 cm ± 2 cm for Ambitious. We further assume that extensive management, characterized by low-intensity use with only occasional mowing or grazing, reflects the potential management conditions of RP-PV sites. Therefore, the wetland category, comprising unused organic soils with varying vegetation and WTD characteristics, was additionally incorporated into the EEG-compliant and Ambitious sub-datapools. The land use categories and WTD thresholds of the three sub-datapools are summarized in Table 2.

The sub-datapools define the sampling basis for the following space-for-time simulations. Each of the three rewetting pathways was simulated under each of the three Peatland-PV deployment scenarios, resulting in nine space-for-time simulations in total. To account for

298 spatial variability in soil and site characteristics, 1,000 stochastic iterations were performed for
299 each simulation. The model randomly selects sites from the respective sub-datapool according
300 to the annual scenario-specific Peatland-PV expansion, with sampling conducted on a point-
301 by-point (hectare-by-hectare) basis.
302
303 For each of the nine space-for-time simulations, GHG emissions were estimated on the basis
304 of the mean across the 1,000 iterations, whereby the drained sub-datapool had a median GHG
305 balance of 36.04 t CO_2-eq ha^{-1} yr^{-1}, compared with 22.66 t CO_2-eq ha^{-1} yr^{-1} (−37.1%) in the
306 EEG-compliant pool and 16.12 t CO_2-eq ha^{-1} yr^{-1} (−55.3%) in the Ambitious pool. For a
307 visualization of the sub-datapools, please refer to Figure 6 in the Appendix. This approach
308 captured the variability arising from the spatial distribution and composition of the respective
309 sub-datapools while incorporating the GHG emission estimates reported in the NIR into the
310 projected trajectories.
311
312 **Tab. 2** Criteria used to define the three sub-datapools from the emission data (UBA 2026) for
313 the space-for-time simulation of rewetting pathways across all scenarios.

Sub-datapool	Drained	EEG-Compliant	Ambitious
Peatland-PV policy	100% DP-PV	100% current EEG framework on RP-PV	100% hypothetical more ambitious EEG framework on RP-PV
Required land use	Grassland	Grassland, Wetland	Grassland, Wetland
Required water table	< -20 cm	-20 cm ± 2 cm	-10 cm ± 2 cm
Sample area [ha]	441157	14874	12421
Resulting median pool GHG emissions [t CO_2-eq ha^{-1}]	36.04	22.66	16.12

314
315
316 # 3. Results
317 ## 3.1 Historical development of the Peatland-PV sector
318 As shown in Figure 1a, the expansion of Peatland-PV systems began in 2000, reaching its first
319 peak in 2011. This period was followed by a significant contraction, culminating in a localized
320 minimum in 2016, during which expansion nearly stagnated. The technology subsequently
321 experienced a steady recovery with accelerating growth rates until today. As of 1 January 2026,
322 a total of 759 individual intersection polygons of GM-PV plants with organic soil aggregating in
323 492 Peatland-PV solar parks (unique MaStR IDs) were identified. The PV panels at these sites
324 covered 1109 ha of organic soils, accounting for 2.7% of Germany's total GM-PV area on that
325 date and 0.06% of Germany's total organic soil area. The full spatial footprint from these 492
326 solar parks (including parts on mineral soils) amounted to 3,276 ha and corresponded to

approximately 3.2 GWp of installed capacity, representing 9.1% of the total German GM-PV capacity, which was approximately 35.1 GWp at that time (Manske 2026).

343 solar parks (648 ha) were installed before 2023, which was the year of the EEG amendment that introduced specific rewetting regulations for Peatland-PV systems. Since this regulatory change, 149 new solar parks (461 ha) have been registered, 112 of which (316 ha) were commissioned in 2024 and 2025. However, these recent installations are mainly DP-PVs and therefore do not yet represent RP-PVs in the sense of the new statutory rewetting requirements.

The PD for Peatland-PV followed the broader trend for Germany's GM-PV sector (Figure 1b). While the initial values were less than 0.3 MWp ha^{-1} in 2000, a significant upward trend was subsequently observed. According to our geodata, the Peatland-PV segment reached a mean PD of 1.25 MWp ha^{-1} in 2025, whereas the reference PD including all the GM-PV systems was 1.32 MWp ha^{-1}.

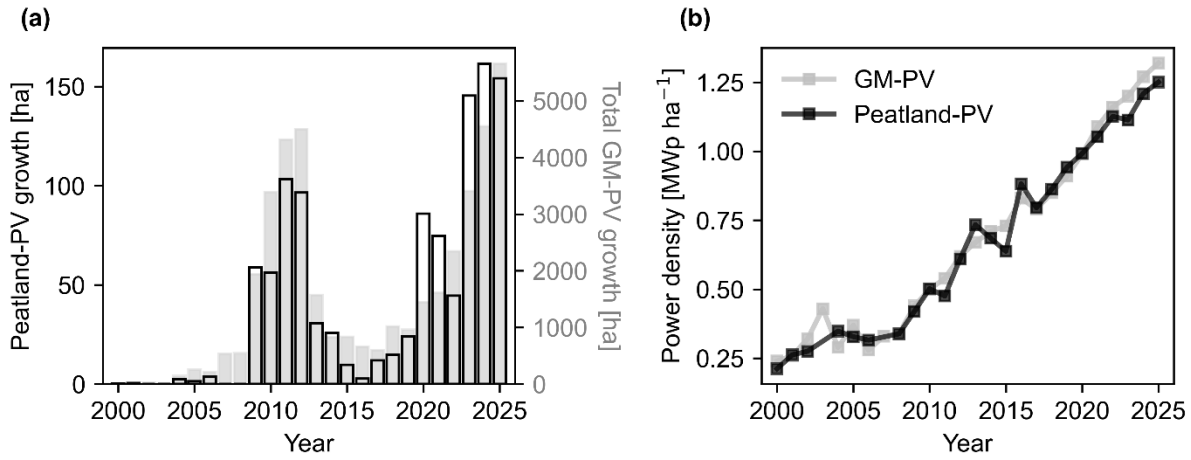


Fig. 1 Historical development of the Peatland-PV segment in Germany **(a)** Annual growth of Peatland-PV (black bars) compared with the total German GM-PV expansion (gray bars) between 1 January 2000 and 1 January 2026 (**b**) Development of annual median power densities from all new GM-PV plants (gray) and those of the Peatland-PV segment (black)

3.2 Status quo analysis of Peatland-PV distribution and soil characteristics

Most identified Peatland-PV plants are located within the Federal State of Bavaria (481 ha, 43.4%), followed by Lower Saxony (183 ha, 16.5%), Schleswig-Holstein (173 ha, 15.6%) and Mecklenburg-Western Pomerania (140 ha, 12.6%). Together, these four federal states account for more than 88% of the total German Peatland-PV area. For the full status quo dataset, please refer to Tab. 4 in the Appendix.

Most Peatland-PV plants are on fen peat, covering 913 ha (82.3%) of the Peatland-PV segment (see Figure 2a). Bog peat is minor at 101 ha (9.1%), and unknown genesis makes

up 95 ha (8.6%). Most of the intersection area (956 ha, 86.2%) shows no mineral cover layers. This matches the baseline characteristics of the national organic soil dataset, where about 85% of the area has no mineral cover layer.

The peat thickness is more heterogeneous, with a medium thickness of 70 to <120 cm covering 386 ha (34.8%), and peat-derived soils on 375 ha (33.8%) being the next largest category. Together, these two classes account for more than two-thirds of the total Peatland-PV area. The remaining peat thickness classes are less common. The 30 to <70 cm category covers 106 ha (9.5%), and the deep peat classes from 120 to 200 cm and >200 cm account for 92 ha (8.3%) and 78 ha (7.0%), respectively. Very shallow peat layers of 10 to <30 cm represent only 31 ha (2.8%), and deep-plowed soils are rare, accounting for only 23 ha (2.1%).
Furthermore, 705 ha (63.6%) lack any limnic sediments, and 379 ha (34.1%) have unspecified Gyttja. The underlying mineral substrate is unknown for 517 ha (46.7%), followed by sandy unconsolidated sediments on 479 ha (43.2%).
The current specific organic soil coverage for each of the 492 Peatland-PV solar parks varies significantly, ranging from negligible contact (< 0.01 ha) to complete placement on organic soil, with an arithmetic mean of 6.6 ha and a median of 2.8 ha (Figure 2b). The global area-weighted coverage fraction is 34%, reflecting the total proportion of the PV panel area of the 492 solar plants that are situated on organic soils (1109 ha from 3276 ha). In contrast, the arithmetic mean intersection ratio of all the Peatland-PV panels was notably greater at 53%.

The analysis of land use information for all 759 intersecting polygons derived from ATKIS®-Basic DLM data revealed that grassland accounts for the largest share, with 523 ha (n = 370), followed closely by cropland, with 514 ha (n = 252). Furthermore, 62 ha (n = 129) remained classified as unknown, whereas only 10 ha (n = 8) were located in areas categorized as wetland. Overall, approximately 94% of the Peatland-PV module area on organic soils is currently located within landscapes characterized by a history of intensive agricultural drainage.

The WTDs of the organic soils from the identified Peatland-PV plants indicate intensive drainage (Figure 2c). Across all sites, the arithmetic median WTD is −0.47 m, and the arithmetic median of GHG emissions amounts to 37.7 t CO_2-eq ha^{-1}. When weighted by area, these medians shift to −0.51 m and 38.7 t CO_2-eq ha^{-1}, respectively. The corresponding means are −0.50 m and 33.9 t CO_2-eq ha^{-1} unweighted and −0.56 m and 35.1 t CO_2-eq ha^{-1} when area weighted. In total, Germany's Peatland-PV area as of 1 January 2026 is associated with soil emissions of 38.9 kt CO_2-eq per year (median, area-weighted).

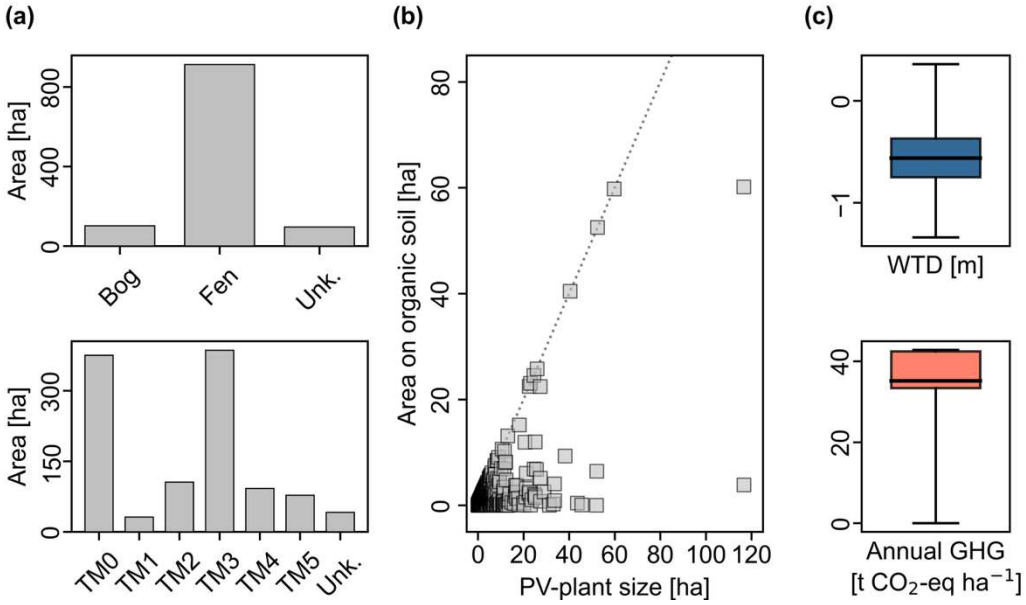


Fig. 2 Characteristics of the identified Peatland-PV plants. (**a**) Distribution of total plant area according to peatland genesis (top) and peat thickness (bottom) on the basis of the classification by Wittnebel et al. (2023): TM0 (peat-derived), TM1 (10 to <30 cm), TM2 (30 to <70 cm), TM3 (70 to <120 cm), TM4 (120 to 200 cm) and TM5 (>200 cm). **(b)** Scatter plot showing the total area of each Peatland-PV plant against its intersection area with organic soils. The dashed 1:1 reference line indicates full placement on organic soils, whereas plants below this line are only partially situated on organic soils. (**c**) Box plots illustrating the area weighted distribution of water table depths (top) and the corresponding annual soil GHG emissions (bottom) from Peatland-PV soils.

3.3 Deployment scenarios of the Peatland-PV sector

The simulation results for the target year 2045 reveal substantial differences in land use shares and energy yields across our three scenarios (Figure 3). The Boost scenario represents the most extensive expansion on organic soils, utilizing 8,031 ha of Peatland-PV panel cover by 2045. The scenario-specific development of PD corresponds to an installed capacity of 10,594 MWp, resulting in an annual generation of approximately 10,065 GWh. The Balance scenario projects a moderate development path with 5,331 ha of Peatland-PV and an installed capacity of 6,333 MWp, yielding 6,016 GWh per year in 2045. In contrast, the most land use-conservative Brake scenario occupies only 2,604 ha, corresponding to 2,785 MWp and an annual energy yield of 2,646 GWh by 2045. For detailed information on the scenario-based Peatland-PV deployment, please refer to Online Resource 1.

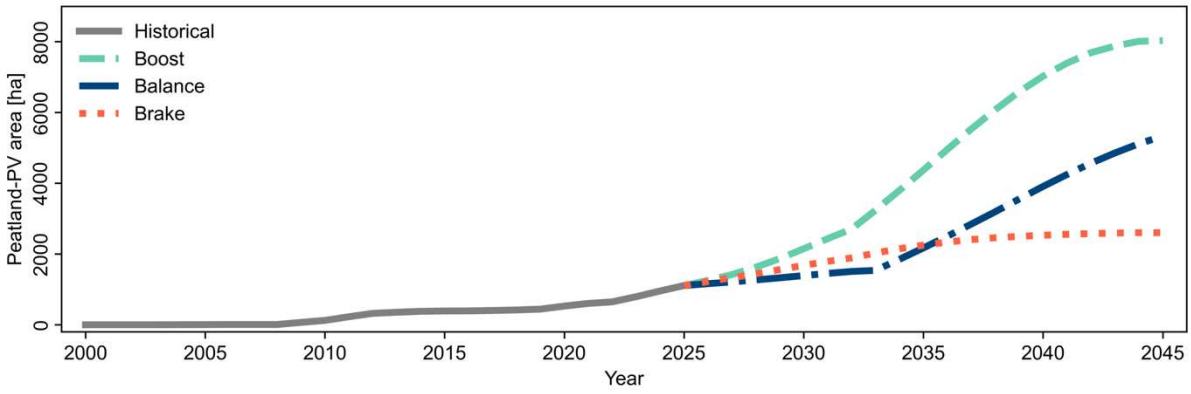


Fig. 3 Land requirements of solar panels from Peatland-PV systems according to historical data and model results. From 2025 onward, the diverging paths highlight the potential range of land occupation according to the three scenarios.

3.4 GHG emission intensities and total annual soil emissions

The Peatland-PV area exhibited an expansion in our scenarios, thereby increasing total annual soil emissions and mitigation potential. The Brake scenario shows slow but steady growth, while the Balance and Boost scenarios show acceleration after 2030, reflecting greater land use.

By 2045, area-weighted organic soil emission intensities for continued drainage stabilize at 34.1 t CO_2-eq ha^{-1} for Boost, 34.2 t CO_2-eq ha^{-1} for Balance, and 34.4 t CO_2-eq ha^{-1} for Brake (Figure 4), resulting in total annual soil emissions of 274 kt CO_2-eq, 182 kt CO_2-eq, and 89 kt CO_2-eq, respectively (Figure 5).

Rewetting significantly improves these balances (Figure 4 and Figure 5). Under the EEG-compliant pathway, in 2045, emissions from the Peatland-PV sector decreased to 22.9 t (Boost), 23.9 t (Balance), and 26.9 t CO_2-eq ha^{-1} (Brake). This decreases total annual emissions to 184 kt (33% mitigation potential), 127 kt (30%), and 70 kt CO_2-eq (21%). The Ambitious rewetting pathway yields even greater reductions, lowering specific emissions to 17.5 t (Boost), 19.0 t (Balance), and 23.4 t CO_2-eq ha^{-1} (Brake). Consequently, annual emissions fall to 141 kt (49% mitigation potential), 101 kt (45%), and 61 kt CO_2-eq (31%). Notably, the Boost–Ambitious configuration represents the only scenario in which avoided soil emissions (~133 kt CO_2-eq) nearly compensate for the remaining emissions from 2045 onward, which are largely driven by older DP-PV plants installed prior to 2026 on previously drained organic soils. The variance of the final GHG emissions across the 1,000 model runs is small, ranging between ±1.3% and ±1.9% from the mean within the individual expansion scenarios and rewetting pathways.

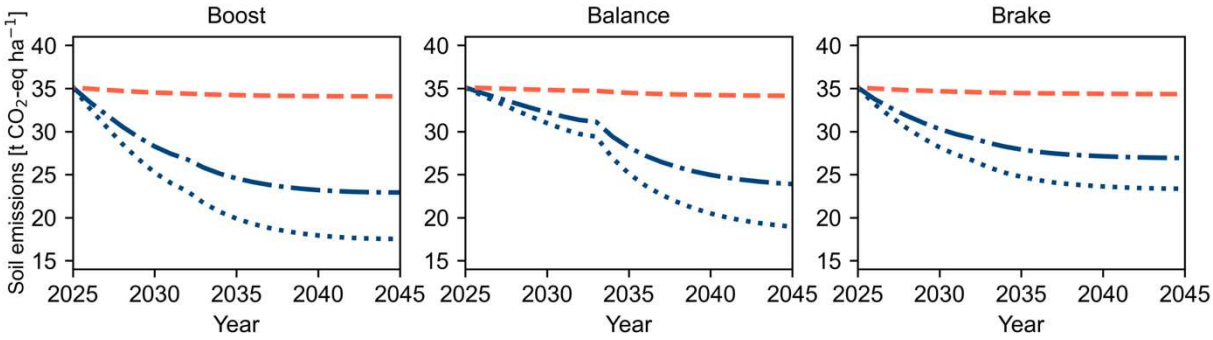


Fig. 4 Area-weighted mean GHG soil emission intensity of Peatland-PV systems per hectare across the expansion scenarios: Boost, Balance, and Brake. The red dashed line indicates the reference development under continued drainage, whereas the dotted lines represent the mitigation potential of different rewetting pathways: EEG-compliant (dash-dotted, blue) and ambitious (dotted, blue)

3.5 Electricity production from Peatland-PV systems and total GHG balance

The annual avoided electricity-related GHG emissions from Peatland-PV follow a nonlinear, approximately parabolic trajectory across all scenarios. Initially, avoided emissions peak around 2025 due to rapid capacity expansion, before decreasing as grid decarbonization reduces the climate benefit of additional PV generation. In the Boost and Balance scenarios, GHG avoidance temporarily flattens between 2025 and 2035, as Peatland-PV capacity expands more slowly than the electricity system decarbonizes. Consequently, a local minimum occurs in 2030 for the Boost scenario, with only 119 kt CO_2-eq of annually avoided emissions, compared to soil emissions of 74 kt CO_2-eq (Drained), 61 kt CO_2-eq (EEG compliant), and 54 kt CO_2-eq (Ambitious), which is shown in Figure 5a. A similar, less pronounced minimum appears in the Balance scenario in 2035, with 100 kt CO_2-eq avoided, against 75 kt (Drained), 61 kt (EEG compliant), and 55 kt CO_2-eq (Ambitious; Figure 5b). In contrast, this intermediate flattening does not occur in the Brake scenario, reflecting slower electricity system decarbonization (Figure 5c).

In 2045, scenario outcomes vary greatly (Table 3 and Figure 5). The Boost scenario eliminates electricity-based GHG emissions as the power sector is already fully decarbonized (Figure 5a). The Balance scenario leaves residual fossil fuels in the electricity mix, allowing the Peatland-PV sector to avoid 66 kt CO_2-eq per year (Figure 5b). The Brake scenario allows an annual avoidance of 112 kt CO_2-eq for the same target year (Figure 5c).

Tab. 3 Area consumption of Peatland-PV solar panels and total annual GHG balances of the Peatland-PV sector according to the three scenarios for the years 2035/2045.

Scenario	Peatland-PV area [ha]	Rewetting pathway	Residual soil emissions [kt CO_2-eq yr^{-1}]	Electricity offsets [kt CO_2-eq yr^{-1}]
Boost: Maximal expansion, electricity sector fully decarbonized by 2045	4,370/8,031	Drained	150/274	198/0
		EEG-compliant	107/184	
		Ambitious	87/141	
Balance: Moderate expansion, residual fossil fuels in the grid by 2045	2,171/5,331	Drained	75/182	100/66
		EEG-compliant	61/127	
		Ambitious	55/101	
Brake: Minimal expansion, very slow grid decarbonization	2,250/2,604	Drained	78/89	165/112
		EEG-compliant	63/70	
		Ambitious	56/61	

A turning point occurs in the net balance around 2039. In both the Boost and Balance scenarios, the Drained pathway's annual soil emissions exceed the annual avoided emissions from electricity generated by the Peatland-PV segment. This reversal is driven by the simultaneous expansion of land requirements from Peatland-PV systems and the projected decrease in the carbon intensity of the displaced electricity mix. In the Brake scenario, this reversal point is not reached within our study period due to slower decarbonization of the electricity mix. Detailed numerical outputs for all scenario trajectories are available in Online Resource 1.

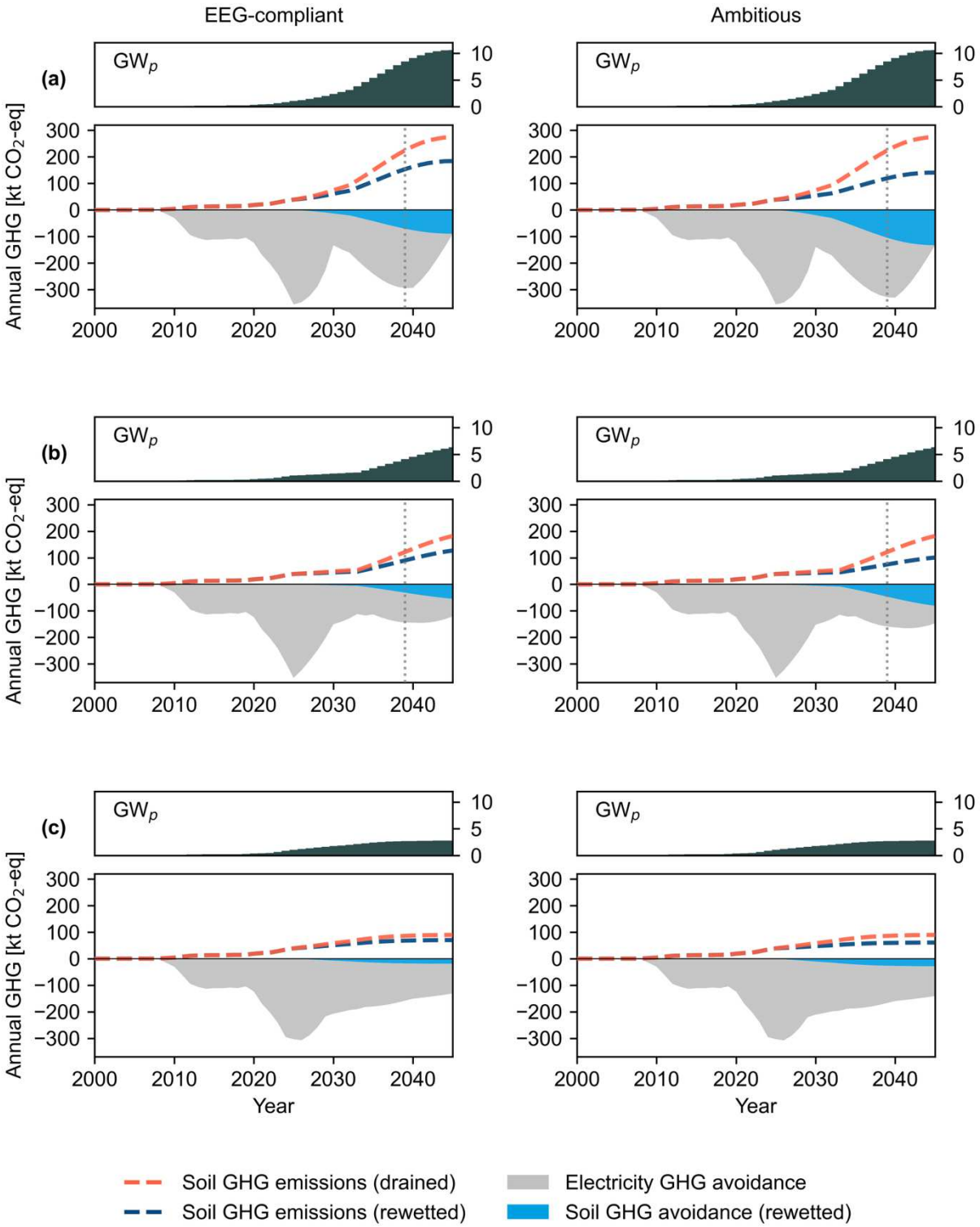


Fig. 5 Cumulative installed capacity in Gigawatt peak (GWp) of the Peatland-PV sector (inset top panels) and associated annual GHG fluxes (main panels) from 2000 to 2045 across expansion scenarios: **(a)** Boost, **(b)** Balance, and **(c)** Brake. Dashed curves delineate potential positive soil emissions: Drained pathway (red dashed line) versus residual emissions under the respective rewetting pathway (blue dashed line). Stacked areas below zero illustrate avoided emissions, partitioned into displaced grid electricity emissions (gray) and avoided soil oxidation achieved via rewetting (light blue). The vertical dotted line marks the tipping point where soil emissions from the Drained pathway exceed annual grid electricity avoidance for the first time (does not occur in Brake)

3.6 Cumulative GHG budgets

The future climate impacts of peatland-PV systems are best understood through the cumulative greenhouse gas (GHG) budgets for the period of 2026 to 2045, representing the remaining time window for rewetting in our study. Over these two decades, the cumulative avoided GHG emissions from substituting fossil grid electricity amount to 6,034 kt CO_2-eq for the Boost scenario, 5,792 kt CO_2-eq for the Brake scenario, and 5,126 kt CO_2-eq for the Balance scenario.

These future savings must be weighed against persistent soil GHG fluxes, as already installed DP-PV plants impose a major burden on these budgets. Notably, the scenarios assume different peatland-PV deployment areas, so the final cumulative soil emission budgets refer to different total areas. Without rewetting (drained pathway), cumulative soil emissions reach 3,502 kt CO_2-eq in the Boost scenario, 2,176 kt CO_2-eq in the Balance scenario, and 1,752 kt CO_2-eq in the Brake scenario. Under EEG-compliant conditions, cumulative emissions decrease to 2,571 kt CO_2-eq in the Boost scenario, 1,751 kt CO_2-eq in the Balance scenario, and 1,489 kt CO_2-eq in the Brake scenario by 2045. More ambitious rewetting would further enhance climate mitigation by lowering cumulative soil emissions to 2,122 kt CO_2-eq in the Boost scenario, 1,547 kt CO_2-eq in the Balance scenario, and 1,362 kt CO_2-eq in the Brake scenario over the same period.

4. Discussion

4.1 Characteristics of the Peatland-PV segment

Our analysis shows a clear historical growth trend in the Peatland-PV sector. In 2023, 793 hectares of organic soil were utilized for PV modules, which is in the same range of the 643 MWp reported by Schwill et al. (2025) for the same year. Our 2025 finding of 876 ha matches the data on the EE-Monitor interactive web platform (UFZ 2026). By 1 January 2026, the Peatland-PV sector had already increased to 1109 hectares.

Legislation in 2023 has been supportive, yet successful RP-PV projects remain rare (Schwill et al. 2025; Seidel et al. 2024). Our results highlight that Peatland-PV plants are mostly realized on drained agricultural land with average WTD levels of approximately −0.5 m. However, WTDs at certain locations may increase over time without initial rewetting measures according to Hohlbein et al. 2026. One possible explanation is the location of many German GM-PV plants along railways and highways, reflecting the incentive structure of the EEG. For drained organic soils, transport infrastructure often interrupts the drainage network. Currently, no systematic observations of water levels in PV plants are available in order to investigate this possible effect.

On the majority of current sites drainage persists, rapid peat degradation continues and resulting substantial GHG emissions counteract the carbon-mitigation benefits of renewable electricity production. Germany's 1109 ha covered with Peatland-PV solar panels currently commit to annual GHG soil emissions of approximately 39 kt CO_2-eq. However, this estimate considers only direct spatial intersection of soil and PV panels. When accounting for the fact that the affected organic soils typically extend beyond plant boundaries, e.g., by applying the hydrological unit factor of 2.74 proposed by Schwill et al. (2025), the actual scale of the impact can quickly become much larger. The continuous GHG release at DP-PV sites will continue for decades, likely extending well beyond Germany's 2045 climate neutrality target year and conflicting with the statutory 2030 target to transform the LULUCF sector into a net carbon sink. Given current deployment rates and the ongoing absence of regulatory construction bans on drained organic soils, such as under Section 35 of the German Federal Building Code (BauGB), we anticipate that these emission trajectories will accelerate further. Ultimately, our findings highlight the critical necessity of adapting the underlying legal frameworks, which have already been proposed in the literature (Helbig et al. 2022; Schwill et al. 2025). A construction ban on drained organic soils could effectively avoid the long-term lock-in of GHG emissions from DP-PV plants.

Nevertheless, such a regulatory ban alone does not guarantee that those organic soils will ultimately undergo rewetting. Recent position papers by organizations advocate for strictly conditioning any Peatland-PV permits upon mandatory rewetting to maximize climate mitigation benefits and render the overall GHG balance of this technology less dependent on the emission factor of the national electricity mix (DNR 2022; GMC 2026; Keinath et al. 2026; KNE 2024; Mehl et al. 2026; NABU 2023). Within this context, it is important to emphasize that, according to our model, the overall GHG balance of Germany's Peatland-PV sector is currently still climate-beneficial, as electricity generation displaces more fossil fuel emissions than organic soils emit. However, this is not an argument against rewetting. Rather, it highlights that adaptation is required on both fronts. Moreover, our conclusion regarding net climate benefits is highly sensitive to the assumed displaced electricity mix, excludes upstream emissions of PV electricity according to standard climate reporting protocols (UBA 2026), and will most likely weaken with further decarbonization of Germany's electricity sector (Keinath et al. 2026; Luderer et al. 2025; Schwill et al. 2025; Thelen et al. 2024; Wirth 2026).

Evaluating the actual climate impact in these areas requires precise data. While Schwill et al. (2025) reported that most German Peatland-PV plants are associated with high organic soil GHG emissions, our study complements this finding by providing the first model-based data on WTD and GHG balances at national scale based on national GHG inventory data,

establishing an important baseline for further discussions on this technology. Consistent with the paper of Schwill et al. (2025), our results show that the current organic soil coverage of Peatland-PV plants varies from minimal (<1.0% intersection) to full cover (100% intersection). However, our calculated coverage ratios of 34% area-weighted and 53% arithmetic means are substantially higher than their reported average sector-wide direct soil-to-plant intersection of 20%. Despite these differences, which may arise from uncertainties in the underlying geodata, both results suggest the same overall pattern. In many cases, Peatland-PV deployment on organic soils seems to occur largely incidentally, while deliberate site selection does occur, but remains rare.

However, these findings rely on the analysis of large-scale geospatial datasets. Therefore, sources of uncertainty in the status quo analysis arise from the spatial accuracy of the underlying geodata itself, particularly regarding the delineation of organic soils and GM-PV plants. While minor intersections (e.g., <1.0%) likely represent spatial artefacts resulting from coincidental boundary overlaps, the likelihood of an artefact decreases sharply with larger intersection shares. Because our national GHG and WTD estimates are derived from an area-weighted average across all intersected areas, these minor boundary artefacts have a negligible impact on the overall results.

Further uncertainty originates from the WTD estimates and associated GHG emissions used in this study, which are themselves derived from spatial models (Tiemeyer et al. 2020). Moreover, assigning these parameters to GM-PV sites via nearest-neighbor when direct model results were missing, introduces uncertainty at the individual plant level. However, because our study evaluates the national Peatland-PV segment rather than single-site performance, these local deviations are not expected to systematically bias the outcome in either direction. Empirical in situ monitoring across operational Peatland-PV sites will nevertheless be valuable to refine future high-resolution models.

In this context, the ongoing MoorPower research project is currently conducting the first high-resolution soil GHG measurements at a Peatland-PV facility via the eddy covariance method. In addition, monitoring data from EEG-funded RP-PV projects could provide a valuable source for model validation, as compliance with the funding scheme requires verification of prescribed WTDs. Making these data available for scientific evaluation would improve the assessment of achieved GHG mitigation.

4.2 The Strategic Role of the Peatland PV sector

Our findings indicate that by 2045, RP-PVs could achieve annual GHG avoidance potential in the kiloton range, spanning a projected PV panel area of 2,604 ha to 8,031 ha. Although this contribution seems minor when contrasted with national climate targets demanding megaton-scale annual emission cuts or when compared against the total national organic soil area of 1.9 million hectares (Wittnebel et al. 2023), such a perspective overlooks the current socioeconomic reality. While it is the declared objective of the German Federal Government to rewet most of the national peatland area (BMUV 2022), Germany's actual rewetting pace is currently lagging behind the trajectories required to meet that target. As highlighted by Wichmann and Nordt (2024), even the most conservative projections, which demand 20,000 ha of rewetting per year, are missed by a factor of ten, given that the actual rewetting rate in Germany averages only approximately 2,000 ha per year (Barthelmes et al., 2021). Furthermore, RP-PV plants could become particularly relevant at the regional level, as peatland-rich federal states pursue their own emission reduction targets. For example, Bavaria alone accounts for more than half of the German Peatland-PV area determined in our study. We assume that this heavy concentration is driven not only by the high solar irradiance in southern Germany, which enhances economic yields compared with northern regions but also by the widespread distribution of prealpine fen peat and state-specific regulatory frameworks that historically favored GM-PV deployment on agricultural land.

The current gap between political rewetting ambitions and actual implementation suggests that additional strategies are urgently needed. RP-PV may not provide the spatial scale needed to meet national targets on its own, given its projected coverage of less than 0.5% of German organic soils. However, it could serve as a local economic enabler, providing the initial capital and land-use incentives necessary to unlock broader, landscape-scale hydrological management. Conventional restoration concepts often struggle with intense land use competition and the lack of long-term economically feasible perspectives for landowners (Seidel et al. 2024). A review of already implemented rewetting projects shows that these are currently conducted primarily through conventional nature conservation and restoration schemes. (Schäfer et al. 2022; Tiemeyer et al. 2020). However, an economically viable after-use following rewetting is currently not given in most cases (Latacz-Lohmann et al. 2023), as pure peatland protection often generates no revenue (Seidel et al. 2024), and markets and supply chains for wet agriculture products (paludiculture) are still in the early stages of development and remain hindered by high conversion and cultivation costs (De Jong et al. 2021; Schwill et al. 2025). Here, RP-PVs could intensify the willingness of landowners to rewet, as Seidel et al. (2024) already noted, through the use of existing value chains and more economically viable options after rewetting. In addition to its economic role, the RP-PV

segment may also provide biodiversity co-benefits, as first evidence indicates positive effects on bird diversity (Martens et al. 2026).

Moreover, from a societal perspective, RP-PVs offer a unique opportunity, as we assume climate avoidance costs of rewetting, which are currently funded through small additional EEG feed-in premiums paid to the operator (0.005 EUR kWh^{-1}), to be small compared with the staggering social costs of carbon (Tol 2025) that would incur if those organic soils remained in a drained state. With this small number of rewetted hectares per year, it can be assumed that if an RP-PV plant is not realized in an agricultural area, this area will remain in the drained condition first at all, therefore continuing to emit high amounts of GHG. This raises the question of whether climate targets, especially rewetting targets, can be reached without the widespread implementation of RP-PVs.

Nevertheless, the soil-based climate mitigation potential of RP-PV plants should not be overestimated. Current Peatland-PV plants are associated with high soil carbon losses and GHG emissions of approximately 38.9 t CO_2-eq ha^{-1} yr^{-1} (median, area weighted). Our sub-datapools indicate that, for new plants, EEG-compliant rewetting may reduce emissions by 41.8% to 22.7 t CO_2-eq ha^{-1} yr^{-1} on average, whereas ambitious rewetting could achieve reduction of 58.6%, lowering emissions to 16.1 t CO_2-eq ha^{-1} yr^{-1}. For the nationwide Peatland-PV sector, however, these reductions are constrained by high emissions from existing DP-PV plants. While our modeled reductions likely represent conservative estimates that could be higher in practice, substantial residual emissions nevertheless persist. Even the Ambitious rewetting pathway does not eliminate GHG emissions entirely, as the targeted WTD represent a compromise between rewetting and PV plant operation. Consequently, RP-PV cannot fully restore the GHG balance of pristine mires or function as a net GHG sink. Therefore, RP-PV should be understood as a form of extensive peatland management that substantially reduces emissions while generating renewable electricity. Accordingly, our results contrast with those of Schwill et al. (2025), whose best-case assessment assumed that rewetting completely eliminates soil GHG emissions.

In this context, several aspects of our scenario model require consideration. Despite the urgency of the topic, peer-reviewed evidence remains limited in some areas, requiring assumptions where empirical data are lacking. This is common in scenario analyses (Wiese et al. 2022) and may influence the results and, in this case, GHG balances. Our study is concerned with the PD of Peatland-PV plants, which is key to spatial footprint assumptions based on projected installed capacities. Some literature suggest lower PD values for RP-PVs of 0.4-0.8 MWp ha-1 or 0.25-0.6 MWp ha-1 (Keinath et al. 2026; Wirth 2026), however, the

lack of onsite validation (Schwill et al. 2025) and unclear underlying calculation methodologies remain. We therefore prioritise our historical Peatland-PV data as PD baseline. The 38.8 MWp facility constructed on 40 hectares in Varel (Lower Saxony) also supports our higher PD assumptions (Solarserver 2026). Ultimately, we argue that technology operating at the gigawatt scale must account for economic realities, as the inherent costs of rewetting may add financial pressure to wider module-row spacings.

Our model also has some uncertainty regarding GHG emissions. First, relying on annual average grid emission factors may overestimate the immediate displacement of fossil fuel generation. PV electricity generation often peaks at midday, but fossil fuels are most critical during the periods of low sunlight and high demand (Wirth 2026). Indeed, high-resolution modeling suggests that avoided emissions of Peatland-PV plants may be lower by 26±9 g CO_2e kWh^{-1} when accounting for hourly mix fluctuations (Schwill et al. 2025). We expect that integrating energy storage will address this mismatch by shifting PV-generated electricity to peak demand hours (Wirth 2026). Dynamic pricing could also lower these effects and maximize the use of renewable energy at the time of production and reduce the use of fossil fuels in periods of low sunlight and high demand (Beranek et al. 2026).

Second, the reliance on current inventory data (UBA 2026) may underestimate soil emissions from drained pathways, as our model does not account for climate-driven feedback loops. For example, a temperature increase of 0.9 °C has been shown to significantly intensify GHG release from drained organic soils (Bockermann et al. 2024). Consequently, the GHG balance of DP-PV plants may become increasingly worse, meaning that the actual mitigation benefit of rewetting may be even greater as global warming progresses.

We argue that these opposing uncertainties, the potential overestimation of grid displacement and the likely underestimation of drained soil emissions in the future, reinforce the same policy conclusion: RP-PV is the most beneficial climate strategy for constructing solar parks on organic soils.

This conclusion is further highlighted by our identification of a critical crossover in the year 2039 within our scenarios Balance and Boost, where GHG emissions from drained organic soils could outweigh the GHG savings from PV electricity production. Notably, this crossover does not occur in the Brake scenario, which yields the highest future GHG electricity savings despite showing the lowest Peatland-PV deployment rate. This is due to a slower projected decarbonization of the national electricity mix, meaning that the generated PV electricity continuously displaces a greater share of residual fossil fuels over the decades compared with the rapidly decarbonizing Boost and Balance scenarios. As scenario studies diverge in regard to predicting the exact decarbonization trajectory of the German power grid (Luderer et al.

2025; Thelen et al. 2024; UBA 2025), this systemic uncertainty further underscores the critical policy requirement of tying Peatland-PV deployment to mandatory rewetting obligations. Ultimately, the primary focus is not the accounting balance of the technology itself, but the realized net reduction in total GHG emissions. Compared to continued deployment on drained sites, mandating rewetting for all Peatland-PV plants could avoid 0.26 to 0.93 Mt CO_2-eq of cumulative soil emissions by 2045 under current EEG standards, rising to 0.39 to 1.38 Mt CO_2-eq under ambitious rewetting conditions. Averting emissions from organic soils delivers a permanent climate benefit that remains entirely decoupled from future electricity grid dynamics. Currently, mandatory rewetting obligations are only enforced as a prerequisite for receiving EEG market premiums. Outside of the EEG funding scheme, a regulatory loophole remains, as building solar parks that are not reliant on receiving a feed-in tariff is possible today (Schwill et al. 2025; Seidel et al. 2024). Strengthening the RP-PV technology within its legal and regulatory framework is therefore highly critical (Keinath et al. 2026).

The necessity of policy improvement is further emphasized by the currently low deployment volumes fund in our study. Although our projected Peatland-PV deployment figures for 2045 are substantially lower than the capacities projected in alternative literature (Agora Agrar 2026; Keinath et al. 2026; Wirth 2026), these differences can largely be explained by our more restrictive assumptions regarding land availability, deployment constraints and implementation rates. Prior studies have often relied on simplified assumptions, either extrapolating potential directly from Germany's general rewetting requirements, resulting in RP-PV deployment estimates of up to 42 GWp (Agora Agrar 2026), or orienting their metrics purely toward the gross technical potential of all available peatland soils (Keinath et al. 2026; Wirth 2026). If RP-PV is intended to play a more strategic role in achieving climate and rewetting targets by unlocking its great technical potential (Keinath et al. 2026), additional incentives beyond the current EEG premium of 0.5 ct kWh^{-1} will likely be required to improve project viability and stimulate deployment.

Our Peatland-PV capacities can be cross-referenced with the 2024 amendment to the EEG, commonly referred to as Solar Package I (*Solarpaket I*). Under the revised framework introduced by § 37d EEG, special solar installations (including RP-PVs, Agri-PVs, and Floating-PVs) are subject to a dedicated two-stage tender procedure. As of September 2026, however, this specific tender segment remains among the provisions subject to EU state aid approval and is therefore not yet in force. The mechanism provides an award volume that scales progressively from 300 MWp in 2024 to 2,075 MWp per year by 2029. Assuming that this annual tender volume remains constant at approximately 2,000 MWp after 2029, a cumulative potential of approximately 40,000 MWp for all special solar installations would exist by 2045.

Our modeling results fit well within this regulatory corridor. The Boost scenario (10,594 MWp in 2045) implies that Peatland-PV captures approximately 26% of this specific market segment, representing a plausible upper limit for RP-PVs considering direct competition with agrivoltaics (Agri-PVs) and higher initial costs associated with rewetting measures. Conversely, the Brake scenario (2,785 MWp in 2045) corresponds to a utilization rate of approximately 6%, reflecting a cautious adoption trajectory where regulatory hurdles and limited economic incentives constrain project realization.

In this context, it must be noted that the EEG is currently in the novelization phase, and it is unclear how changes will influence future deployment of Peatland-PV systems and could hinder possible rewetting. Whether Germany's new funding directive on paludiculture (PALU-RL 2026) can be effectively combined with the EEG remains to be demonstrated by future commercial projects, as no experiences exist up to now (Keinath et al. 2026). The current version of the EEG in practice shows that few new projects have been awarded subsidies as RP-PV systems. It often takes some time for subsidies and funding programs to become widely known and gain broader practical application. A similar trend has been observed with Agri-PVs, and the possibility of securing funding through innovation tends (Pump et al. 2024). In some cases, however, initial practical experience from early adopters is also needed.

5. Conclusion

While the RP-PV technology alone will not reduce GHG emissions at the scale required to achieve national climate targets, it represents an efficient and promising climate mitigation measure for Germany. Although the achieved soil GHG emission reductions remain below those attainable through the full restoration of intact peatland ecosystems, this is particularly relevant given that peatland rewetting in Germany is currently progressing far too slowly to meet restoration and climate targets, whereas alternative large-scale mechanisms capable of rapidly increasing rewetting rates remain limited.

Most existing Peatland-PV plants are currently located on deeply drained organic soils (approximately -0.5 m WTD). Legislative changes will determine whether upcoming projects continue to be developed on drained peatlands or whether the combination of PV deployment and rewetting becomes economically more attractive, enabling wider implementation. Conversely, continued deployment of DP-PVs may lock in soil GHG emissions in kiloton range for decades, extending well beyond Germany's 2045 climate neutrality target. In contrast, systematic rewetting has the potential to significantly reduce these emissions, thereby ensuring that solar electricity from Peatland-PVs is genuinely green in practice, not merely in name.

Against this background, any revision of existing support schemes for RP-PV should consider how comparable mitigation outcomes for drained peatlands could be achieved through alternative measures. Rather than weakening existing support, the regulatory framework could instead be further strengthened to maximize the potential of this dual-use climate mitigation technology. In particular, mandatory rewetting requirements and additional incentives linked to verified emission reductions and ecosystem services could accelerate the deployment dynamics of this sector and unlock greater climate benefits from both renewable energy generation and peatland restoration.

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Appendix

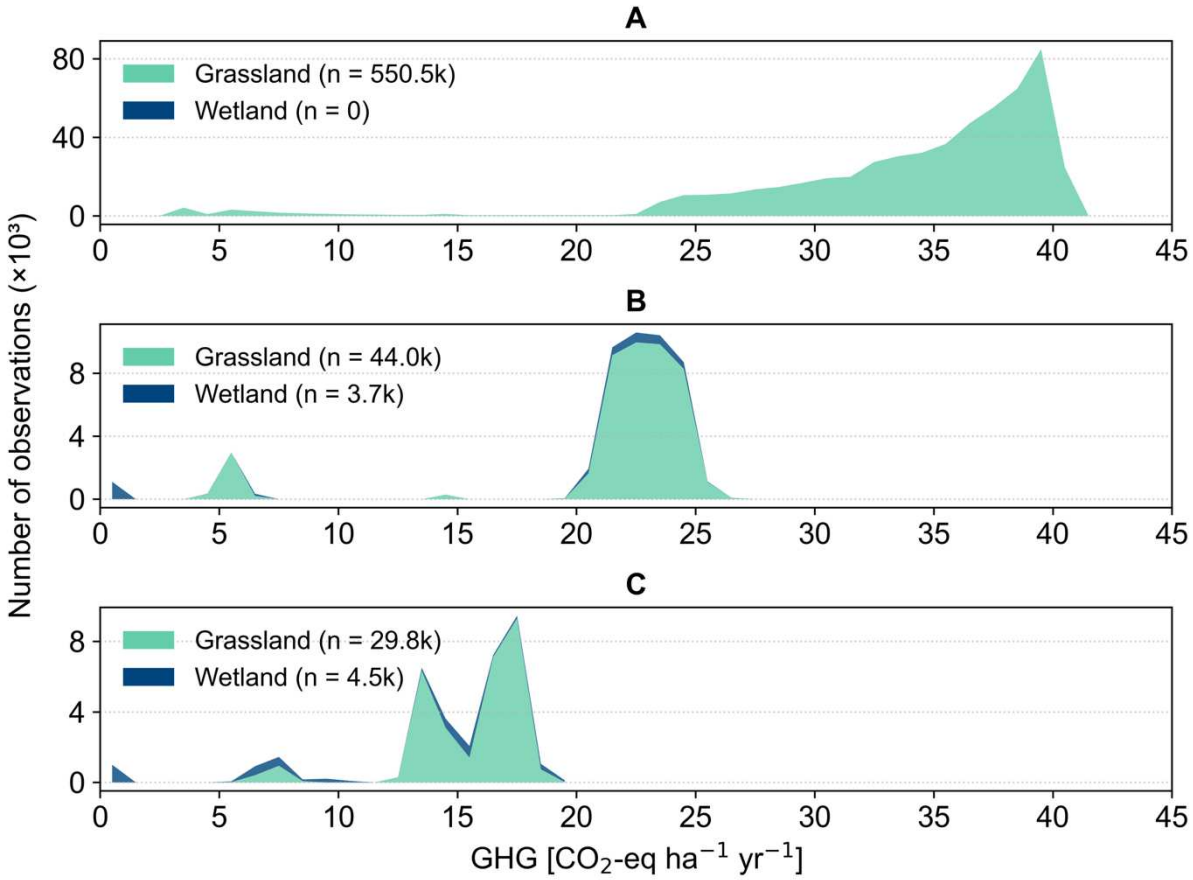


Fig. 6 Frequency distributions of sample points across the three empirical sub-data pools used for the space-for-time simulation. The Drained pool **(A)** consists exclusively of drained grassland sites, whereas the EEG-compliant **(B)** and Ambitious **(C)** pools comprise both grassland (green) and rewetted wetland (blue) sample points. For each rewetting pathway, 1,000 sampling iterations were drawn from these respective distributions to quantify variability and uncertainty in soil GHG trajectories. Observation counts are displayed as stacked distributions; the y-axis scale in panel A differs from panels B and C due to substantial differences in sample size.

Tab. 4 Total evaluated Peatland-PV area comprises 1,109 ha as of January 1, 2026. Values denote the area occupied by solar panels per category (in hectares) and the corresponding percentage share. Soil classification parameters are adapted from Wittnebel et al. (2023), with English translations of the original German designations.

Soil Parameter (original)	Soil parameter (translated)	Classification (original)	Classification (translated)	Area [ha]	Share [%]
BL	Federal state	by	Bavaria	480.77	43.4
BL	Federal state	ni	Lower Saxony	183.07	16.5
BL	Federal state	sh	Schleswig-Holstein	173.0	15.6
BL	Federal state	mv	Mecklenburg-Western Pomerania	139.72	12.6
BL	Federal state	bb	Brandenburg	57.35	5.2
BL	Federal state	st	Saxony-Anhalt	32.04	2.9
BL	Federal state	sn	Saxony	15.56	1.4
BL	Federal state	bw	Baden-Württemberg	12.41	1.1
BL	Federal state	nw	North Rhine-Westphalia	7.21	0.7
BL	Federal state	rp	Rhineland-Palatinate	4.06	0.4
BL	Federal state	he	Hesse	2.86	0.3
BL	Federal state	th	Thuringia	0.52	0.0
BL	Federal state	hh	Hamburg	0.18	0.0
GENESE	Peatland genesis	NH	Fen peat	912.51	82.3
GENESE	Peatland genesis	HH	Raised bog peat	101.23	9.1
GENESE	Peatland genesis	XH	Peat substrate, genesis unknown	95.01	8.6
DECKE	Mineral cover layer	DK0	No mineral cover layer	956.14	86.2
DECKE	Mineral cover layer	DK2b	Thickness 30 to <70 cm, cohesive substrate	53.83	4.9
DECKE	Mineral cover layer	DK3b	Thickness 70 to <100 cm, cohesive substrate	47.72	4.3
DECKE	Mineral cover layer	DK2s	Thickness 30 to <70 cm, sandy substrate	31.1	2.8
DECKE	Mineral cover layer	DK1b	Thickness 10 to <30 cm, cohesive substrate	12.06	1.1
DECKE	Mineral cover layer	DKXb	Thickness unknown, cohesive substrate	4.53	0.4
DECKE	Mineral cover layer	DK1s	Thickness 10 to <30 cm, sandy substrate	2.68	0.2
DECKE	Mineral cover layer	DKXx	Thickness unknown, substrate unknown	0.52	0.0
DECKE	Mineral cover layer	DK2x	Thickness 30 to <70 cm, substrate unknown	0.12	0.0
DECKE	Mineral cover layer	DK3x	Thickness 70 to <100 cm, substrate unknown	0.05	0.0
TORFMAECHT	Peat thickness	TM3	Thickness 70 to <120 cm	385.7	34.8
TORFMAECHT	Peat thickness	TM0	No peat or organic gyttja layer; includes soils with only degraded	375.08	33.8

			peat horizons or deep-ploughed soils		
TORFMAECHT	Peat thickness	TM2	Thickness 30 to <70 cm	105.51	9.5
TORFMAECHT	Peat thickness	TM4	Thickness 120 to <200 cm	92.01	8.3
TORFMAECHT	Peat thickness	TM5	Thickness ≥200 cm	77.74	7.0
TORFMAECHT	Peat thickness	TMX	Peat thickness unknown	41.32	3.7
TORFMAECHT	Peat thickness	TM1	Thickness 10 to <30 cm	31.38	2.8
ABMOORIGKE	Degraded peat horizon	AB0	No degraded peat horizon	757.09	68.3
ABMOORIGKE	Degraded peat horizon	ABb	Degraded peat horizon present, cohesive substrate	185.02	16.7
ABMOORIGKE	Degraded peat horizon	ABs	Degraded peat horizon present, sandy substrate	166.55	15.0
ABMOORIGKE	Degraded peat horizon	ABx	Degraded peat horizon present, substrate unknown	0.08	0.0
TIEFUMBRUC	Deep ploughing	TR0	No deep ploughing	1085.32	97.9
TIEFUMBRUC	Deep ploughing	TR1	Deep ploughing present	23.43	2.1
MUDDE	Underlying gyttja	MD0	No gyttja underlying the peat or degraded peat horizon	704.92	63.6
MUDDE	Underlying gyttja	MDx	Gyttja type unknown	378.63	34.1
MUDDE	Underlying gyttja	MDm	Other mineral gyttja	24.63	2.2
MUDDE	Underlying gyttja	MDh	Organic gyttja	0.56	0.1
MUDDE	Underlying gyttja	MDk	Calcareous gyttja	0.0	0.0
UNTERLAGER	Underlying mineral substrate	LGx	Substrate unknown	517.3	46.7
UNTERLAGER	Underlying mineral substrate	LGs	Sandy substrate	478.62	43.2
UNTERLAGER	Underlying mineral substrate	LGl	Loamy substrate	69.8	6.3
UNTERLAGER	Underlying mineral substrate	LGb	Cohesive substrate, where the substrate cannot be clearly classified as loamy, silty, or clayey	16.81	1.5
UNTERLAGER	Underlying mineral substrate	LGt	Clayey substrate	16.34	1.5
UNTERLAGER	Underlying mineral substrate	LGu	Silty substrate	9.58	0.9
UNTERLAGER	Underlying mineral substrate	LGf	Bedrock	0.31	0.0

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- OnlineResource1.csv