INNOVATIONS IN AGRICULTURAL LAND USE: OPPORTUNITY COSTS OF REWETTING AGRICULTURALLY USED ORGANIC SOILS IN GERMANY

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Abstract

Reducing GHG emissions from agriculturally used organic soils through rewetting makes current land use practices unfeasible and thereby causes costs that go beyond the technical measures of rewetting. Farmers have to forgo the profits that could be achieved with the drained use of organic soils. We estimate the opportunity costs based on a crop-type map generated with remote sensing technologies combined with standard gross margins for the short-term and tenure fees for the long term at the municipality level.

We estimate the average short-term opportunity costs of rewetting one hectare of organic soil ranging from 580 € in Brandenburg to 2.030 € in Lower Saxony. Relating the short-term op-portunity costs to the GHG mitigation potential of rewetting organic soils yields mitigation costs between 20 and 68 €/t CO2eq. This is substantially below the estimated economic welfare losses of 237 € per ton of CO2 emitted (UBA, 2023b).

Recently introduced federal state-specific interventions for peatland protection measures under the second pillar of the “Common Agricultural Policy" (CAP) cover the average short-term opportunity costs of rewetting if combined with other CAP second pillar interventions. How-ever, the interventions do not capture the high variability of opportunity costs within a federal state. Our results contribute to the design of region- and farm-type-specific compensation measures to make rewetting attractive to farmers. Furthermore, they are relevant for a cost-benefit analysis of rewetting agriculturally used organic soils. Finally, they can inform debates on rewetting organic soils in other EU member states.

Keywords

land use analysis, agricultural income, peatland protection measures, CAP

1 Introduction

Peatlands cover 3 to 4% of the global land area (OLSSON et al., 2019). Due to drainage, about 12% of this area is no longer naturally water-saturated (UNEP, 2022). Whenever peatlands are drained, the soil organic carbon gets decomposed, resulting in carbon dioxide emissions that account for about 5% of total global greenhouse gas (GHG) emissions (OLSSON et al., 2019).

In Germany, about 1.3 million hectares of agricultural land are located on drained organic soils (TIEMEYER et al., 2020). Although this is only 7% of the total agricultural land (DESTATIS, 2021a), it is responsible for more than 40% of the total GHG emissions from agriculture and agricultural land use (UBA, 2023a). Therefore, halting carbon decomposition processes by re-wetting organic soils became important in the scientific and political discourse about reducing agricultural GHG emissions (BMUV, 2022; GRETHE et al., 2021).

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Farmers and other stakeholders currently relying on the drained use of organic soils have a critical perspective on rewetting organic soils (BUSCHMANN et al., 2020). Reasons for this include the high costs and the irreversibility of rewetting, as well as the uncertainty about the feasibility and economic viability of wet land use alternatives such as paludiculture (LATACZ-LOHMANN et al., 2019). Farmers fear losing their favored occupation or at least expect a deterioration in the current income situation (NORDT et al., 2022).

As the rewetting of organic soils only aims at raising the water table to the soil surface and not necessarily at restoring the natural conditions of a peatland, there are wet land use alternatives available that may contribute to compensate for the opportunity costs incurred. One can distinguish two economically promising types of wet land use alternatives. Rewetted peatlands could be used in paludiculture, which is characterized by the peat-conserving cultivation of plants adapted to wet conditions (WICHTMANN and JOOSTEN, 2007). A second opportunity is to build photovoltaic plants on peatlands (FAKHARIZADEHSHIRAZI and RÖSCH, 2023). Theoretically, either the profits from producing biomass in paludiculture or the profits from generating energy with photovoltaic plants have the potential to compensate for the opportunity costs associated with the termination of drainage-based land use activities (BÖHM et al., 2022; WICHMANN et al., 2022). However, neither the large-scale application of paludiculture nor the installation of photovoltaic plants on rewetted peatlands has been implemented at scale yet.

It follows, that wet land use practices currently do not provide a sufficient income alternative for farmers. As long as this is the case, additional financial transfers could increase the willingness of farmers to rewet (BUSCHMANN et al., 2020; SCHÄFER et al., 2022). Financial transfers can be provided either by the private sector in terms of purchasing carbon credits to voluntarily offset GHG emissions or by the public sector in terms of subsidies paid for the provision of public services (WICHMANN, 2018).

The largest public agricultural funding instrument in the European Union is the “Common Agricultural Policy” (CAP) (Regulation (EU) 2021/2115). Interventions intended to compensate for income losses resulting from the rewetting of organic soils are implemented under the second pillar of the CAP (EL-0101-03/-04) and are paid annually. Such payments are often accompanied by one-off payments covering initial investment costs (PABST et al., 2018; BMEL, 2023). In addition to the second pillar interventions of the CAP the “European Regional Development Fund” is used to cofinance investments in peatland protection measures (WICHMANN, 2018). In the coming years, the German “Action Program for Natural Climate Protection” (Aktionsprogramm Natürlicher Klimaschutz) will become an important national instrument to finance costs related to peatland protection measures (BMUV, 2023).

Determining appropriate levels of income compensation requires knowledge of the opportunity costs of rewetting and, thus, of the current use and profitability of drained organic soils. Abandoning drainage-based land use on organic soils affects crops that are directly marketed (e.g., wheat) and forage crops (grassland, silage maize) predominantly used to feed the farm’s own livestock. If losses in forage areas cannot be compensated by exceeding the roughage production elsewhere, farmers are forced to reduce the number of ruminants kept (SCHALLER, 2014). This is particularly the case in regions with a high share of organic soils in the total agricultural area (KRIMLY et al., 2014). Consequently, the opportunity costs of forage areas are related to the income generated with ruminants dependent on the roughage from the rewetted area, while the opportunity costs of land cultivated with marketable crop types solely depend on the income generated with these crop types.

Shortly after rewetting, and thus after abandoning drainage-based land use activities, the opportunity costs exceed the foregone income. This is because not all of the cost components can be eliminated immediately (RÖDER and OSTERBURG, 2012). Fixed costs (e.g., machinery, employees, buildings) do not directly depend on the scope and intensity of production processes and cannot be eliminated immediately after the discontinuation of a production process. It follows that the foregone gross margins (revenues minus variable costs) can be taken as an indicator of the short-term opportunity costs. In contrast, the foregone profits (revenues minus all costs, including family owned labor and capital which may be used in other activities) indicate the long-term opportunity costs of rewetting organic soils (RÖDER and OSTERBURG, 2012). We use current tenure fees as a proxy for these profits.

Our study aims to enhance the knowledge about the agricultural use of peatlands and the opportunity costs of rewetting organic soils at the municipality, county, and federal state levels in Germany. Our analysis builds upon previous studies that determined opportunity costs either based on data with a lower spatial resolution (KOPPENSTEINER et al., 2023; RÖDER and GRÜTZMACHER, 2012; RÖDER and OSTERBURG, 2012) or only for selected regions of Germany (KRIMLY et al., 2014; SCHALLER, 2014). Our results contribute to the current discourse about potential areas for peatland protection measures. Furthermore, we provide data to determine appropriate levels of income compensation that economically incentivize farmers to rewet their land. In this context, we compare our results with the corresponding CAP interventions and derive conclusions for future interventions.

2 Material and methods

2.1 Research area

We analyze the whole area of organic soils according to the German definition (TIEMEYER et al., 2020; UBA, 2023a). Organic soils consist of the soil types peatland (soil organic matter (dry mass) ≥ 30%, thickness ≥ 30 cm) and peaty soil (soil organic matter (dry mass) ≥ 15%, thickness 10 - 40 cm (Ad-hoc-AG Boden et al., 2005)). TEGETMEYER et al. (2021) compiled a map according to this definition of organic soils for the whole of Germany (in the following: *organic soil map).* Since only 73% of all organic soils are agriculturally used (TIEMEYER et al., 2020), forests, shrublands, settlements, and other non-agricultural land use categories located on organic soils are excluded from the analysis.

2.2 Land use analysis

Estimating the opportunity costs of rewetting organic soils requires detailed knowledge of their current use, as the profitability depends on the land use that is to be abandoned. The site-specific identification of land use has been a major obstacle in the past (KOPPENSTEINER et al., 2023; RÖDER and OSTERBURG, 2012; WICHMANN et al., 2022). The data either has a limited differentiation of crop types ("Digital Basic Landscape Model", major land use categories), a low spatial resolution ("Agricultural Census", county level is the highest spatial resolution) or is difficult to access ("Integrated Administration and Control System", strict data protection requirements).

The working group THÜNEN EARTH OBSERVATION (2023) overcomes these limitations: Based on remote sensing technologies, BLICKENSDÖRFER et al. (2022) have developed a method to create raster maps depicting cultivated crop types at a site-specific spatial resolution with an overall accuracy of about 80%. TETTEH et al. (2021) developed a method to delineate the field boundaries using majority voting to identify the most likely crop cover from the raster map and to further increase the accuracy. The result is a *parcel-based vector crop type map* (in the following: *crop type map)* that depicts a single crop type for each field. Our analysis is carried out using the crop type map for the year 2020. Interannual variations due to crop rotations are expected to balance out on average.

In addition to analyzing the cultivated crop types, ruminant husbandry is highly dependent on regional forage areas and therefore included in the analysis. The *crop type map* does not provide information about livestock densities nor distinguishes between cereal and silage maize. Information to estimate these parameters is taken from THÜNEN AGRARATLAS (2022). The *agricultural atlas* depicts harmonized estimations of land use and livestock densities at the municipality level (GOCHT and RÖDER, 2014). When estimating the number of ruminants dependent on forage from organic soils, information about the share of silage maize used as a forage crop and silage maize used as a fermentation substrate for biogas plants is required. This information is taken from the "German Maize Committee" which annually commissions surveys (c. 2.000 surveyed farms) to estimate the shares of biogas and forage maize at the federal state level (KYNETEC, unpublished).

The *organic soil map*, the *crop type map,* and the *agricultural atlas* are merged and analyzed in ArcGIS ArcMap 10.8.2. This produces a dataset with information on the crop type cultivated on each parcel located on organic soils and the municipality in which each parcel is located. Each parcel indicated by the *crop type map* as being cultivated with maize is divided by the municipality-specific share of silage and cereal maize given in the *agricultural atlas*. The fraction of silage maize is further divided based on its intended use, taking into account the federal state-specific shares of biogas and forage maize obtained from KYNETEC (unpublished).

To allocate the number of ruminants kept in a municipality (*agricultural atlas*) to its forage area, the average net energy yield of the different forage crop types is considered. For this purpose, a total fictive net energy yield of all forage areas within a municipality is determined by multiplying the area of each forage crop type (*agricultural atlas*) by the corresponding average net energy yield per hectare (DILGER and FAULHABER, 2006). In the second step, the total number of ruminants, categorized by ruminant type, kept within the municipality (*agricultural atlas*) is divided by the total fictive net energy yield. The result is a municipality-specific number of ruminants, categorized by ruminant type, fed with one fictive energy unit. This number is multiplied by the fictive net energy yield of each forage parcel located on organic soils and gives the number of ruminants, categorized by ruminant type, dependent on roughage from the parcel. The land use data obtained at the parcel level is aggregated to higher regional levels.

2.3 Short-term opportunity cost analysis

The short-term opportunity costs of abandoning drainage-based land use activities on organic soils are determined based on the land use data generated at the municipality level (chapter 2.2) and the crop type and ruminant type specific standard gross margins published by KTBL (2023) at the administrative district level (NUTS 2) and averaged over five years (2016/17 – 2020/21).

Standard gross margins are based on product-related revenues and exclude decoupled subsidies (SAUER and HARDEWEG, 2019). This is in line with the recent CAP regulation, whereby organic soils retain their general subsidy eligibility if they are rewetted and used with wet land use alternatives (Regulation (EU) 2021/2115).

The short-term opportunity costs of rewetting a parcel previously cultivated with a certain crop type equal the standard gross margin that could be earned with this crop type. Consequently, the average short-term opportunity costs of rewetting are a weighted combination of all the standard gross margins corresponding to the crops that are to be abandoned. This approach neglects the possibility of farms adjusting their production program. This leads to an overestimation of the short-term opportunity costs, as farmers could adjust their production programs in order to maintain the most profitable production activities. However, this approach circumvents the need for farm individual data (KRIMLY et al., 2014).

To account for the different degrees to which ruminant husbandry is affected by rewetting, a range of short-term opportunity costs is given. The lower boundary of short-term opportunity costs assumes that the rewetting of forage areas has no impact on ruminant husbandry. Forage areas are treated as surplus forage areas. The standard gross margins for surplus forage areas provided by KTBL (2023) are applied. The upper boundary assumes that losses in the forage area cannot be compensated at all. In this case, the short-term opportunity costs of a forage area equal the sum of the standard gross margins that could be earned with the ruminants assigned to that area (SCHALLER, 2014).

2.4 Long-term opportunity cost analysis

The long-term opportunity costs of rewetting agriculturally used organic soils are estimated based on tenure fees provided by DESTATIS (2021b). This follows the approaches of RÖDER and OSTERBURG (2012) and SCHALLER (2014). DESTATIS (2021b) distinguishes the tenure fees by the land use categories arable land, permanent grassland, and other agricultural areas at the federal state level for 2020. Regional differences, which undoubtedly exist, cannot be adequately reflected in this. However, a more detailed spatial resolution that distinguishes between land use categories is not available for all federal states. The tenure fees are weighted based on each land use category's share in the total productive agriculturally used area on organic soils at the municipality level.

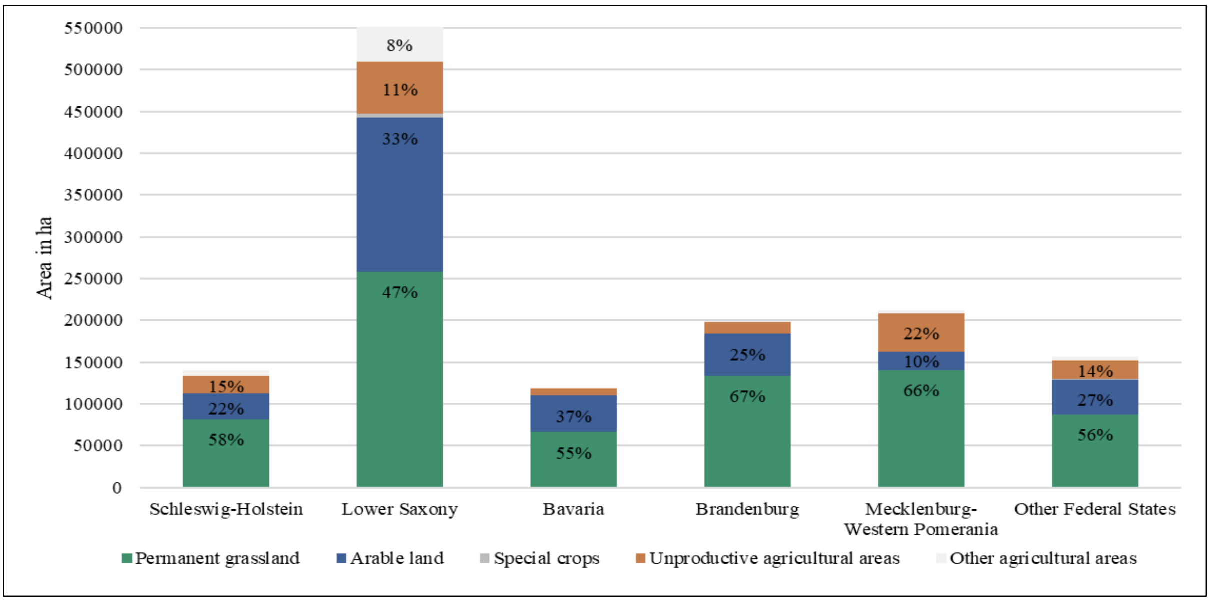
3 Results

3.1 Agricultural land use of organic soils

To place the results about the agricultural use of organic soils in context, they are compared with the agricultural land use on all soils (mineral and organic). The reference data for this comparison is taken from the Agricultural Census 2020 (DESTATIS, 2021a; THÜNEN AGRARATLAS, 2022). Organic soils are unequally distributed among the German federal states. Almost 90% of the organic soils are located in five out of 16 federal states: Lower Saxony (40% of total agriculturally used organic soils), Mecklenburg-Western Pomerania (15%), Brandenburg (14%), Schleswig-Holstein (10%), and Bavaria (9%).

Agriculturally used organic soils can be divided into five land use categories (Figure 1). Permanent grassland covers two-thirds of the productive agricultural area. Arable land and special crops account for the other third. This is in contrast to the total agricultural area in Germany, where permanent grassland accounts for less than one third of total agricultural land.

Figure 1: Land use categories on agriculturally used organic soils

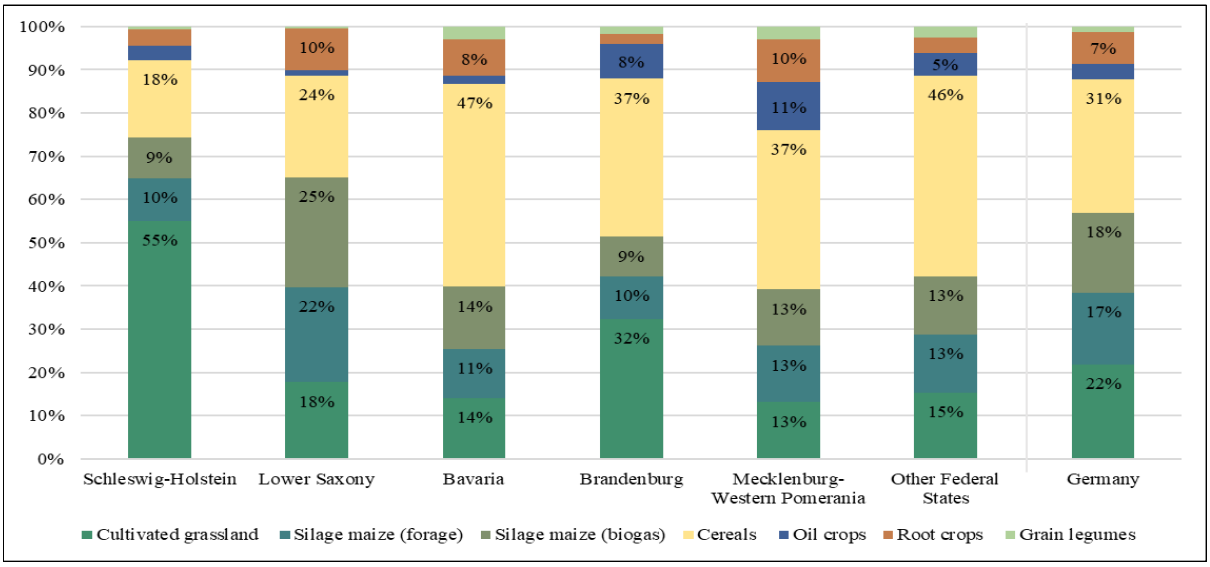


Source: Own illustration and calculations, based on DESTATIS, 2021a; TEGETMEYER et al., 2021; THÜNEN EARTH OBSERVATION, 2023.

In addition to the large proportion of permanent grassland used for roughage production, the arable land on organic soils is also predominantly used to cultivate arable forage crops (57%, Figure 2). Cereals are the main crop group with the second-largest share of arable land located on organic soils (31%). The remaining 12% is split between the main crop groups of root crops (7,5%), oil crops (3,5%), and grain legumes (1%).

In Figure 2, the main crop group of arable forage crops is divided by its crop types and by the use of silage maize. This differentiation allows to exclude the silage maize cultivated for biogas production from the forage area used to produce roughage for ruminant husbandry (real forage area: permanent grassland, cultivated grassland, silage maize (forage)).

Figure 2: Arable forage crops and main crop groups of arable land on organic soils

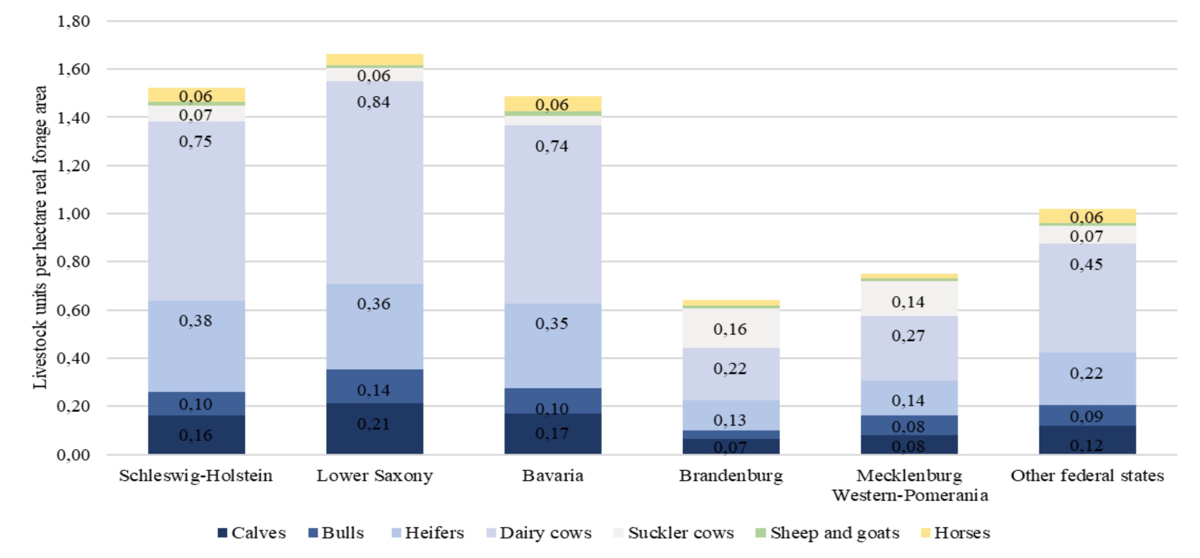


Source: Own illustration and calculations, based on KYNETEC, unpublished; TEGETMEYER et al., 2021; THÜNEN AGRARATLAS, 2022; THÜNEN EARTH OBSERVATION, 2023.

3.2 Ruminant husbandry on organic soils

Forage crops (excl. biogas maize) are cultivated on 80% of all productive agriculturally used organic soils in Germany. Approximately 13% of all ruminants in Germany, are fed with roughage from organic soils. Lower Saxony is the federal state with the most ruminants dependent on roughage from organic soils and with the highest ruminant livestock density per hectare of real forage area on organic soils (1,66 LU/ha, Figure 3). Similar livestock densities can be observed in Schleswig-Holstein and Bavaria. Ruminant husbandry in Brandenburg and Mecklenburg-Western Pomerania is characterized by low livestock densities and a high share of suckler cows.

Figure 3: Ruminant livestock density on real forage area located on organic soils



Source: Own illustration and calculations, based on KYNETEC, unpublished; TEGETMEYER et al., 2021; THÜNEN AGRARATLAS, 2022; THÜNEN EARTH OBSERVATION, 2023.

3.3 Average opportunity costs of rewetting agriculturally used organic soils

The average short-term opportunity costs vary between 190 and 2.142 €/ha*a (Table 1). The overall average of short-term opportunity costs (upper boundary) amounts to 1.457 €/ha*a. Within the same region, rewetting permanent grassland typically results in lower short-term opportunity costs than rewetting arable land. This is due to low market prices paid for surplus roughage (KTBL, 2023) and lower livestock densities compared to arable forage areas. Furthermore, certain marketable crops (e.g., potatoes) generate higher standard gross margins per hectare than ruminant husbandry. In the German average, the short-term opportunity costs (upper boundary) of rewetting a hectare of arable land amount to 1.651 €/ha*a. This exceeds the short-term opportunity costs of rewetting permanent grassland by about 500 €/ha*a.

Regardless of the crop type aggregation considered, the average short-term opportunity costs of Schleswig-Holstein, Lower Saxony, and Bavaria are substantially higher than those of Brandenburg and Mecklenburg-Western Pomerania. One reason is the higher ruminant livestock density. Furthermore, dairy cows generating high standard gross margins are the dominant ruminant type. Another reason is the generally higher soil productivity of land in the western and southern federal states, which is reflected by higher standard gross margins per crop type as well as higher tenure fees.

Larger proportions of arable crop types with high standard gross margins (potatoes, wheat, cereal maize) are the reason for higher short-term opportunity costs (lower boundary) of rewetting arable land in Lower Saxony and Bavaria compared to Schleswig-Holstein. The arable land on organic soils in Brandenburg is predominantly covered by crops with low standard gross margins (rye, sunflowers, cultivated grassland), while the arable land of Mecklenburg-Western Pomerania is to a larger extent covered by wheat, potatoes, and rapeseed, which are arable crop types providing comparatively high standard gross margins.

The average long-term opportunity costs amount to 341 €/ha*a for Germany as a whole. At 330 to 420 € per hectare, the opportunity costs in Lower Saxony, Schleswig-Holstein, and Bavaria are more than twice as high as in Mecklenburg-Western Pomerania and Brandenburg.

Table 1: Average opportunity costs of rewetting agriculturally used organic soils

Average opportunity costs in €/ha*a	Short-term						Long-term
	Productive agricultural area incl. special crops		**Productive arable land excl. special crops**		**Permanent grassland**		**Productive agricultural area incl. special crops**
	lower boundary	upper boundary	lower boundary	upper boundary	lower boundary	upper boundary	
Schleswig-Holstein	560	1.662	717	2.142	478	1.461	371
Lower Saxony	907	2.028	1.070	2.016	379	1.644	422
Bavaria	887	1.731	1.123	1.692	481	1.516	331
Brandenburg	271	578	333	647	187	492	141
Mecklenburg-Western Pomerania	307	768	855	1.262	190	659	180
Germany	**646**	**1.457**	**881**	**1.651**	**318**	**1.156**	**341**

Source: Own calculations based on DILGER and FAULHABER, 2006; DESTATIS, 2021b; KTBL, 2023; KYNETEC, unpublished; TEGETMEYER et al., 2021; THÜNEN AGRARATLAS, 2022; THÜNEN EARTH OBSERVATION, 2023.
Remark: Data land use: 2020, data standard gross margins: 2016-2021, data tenure fees: 2020.

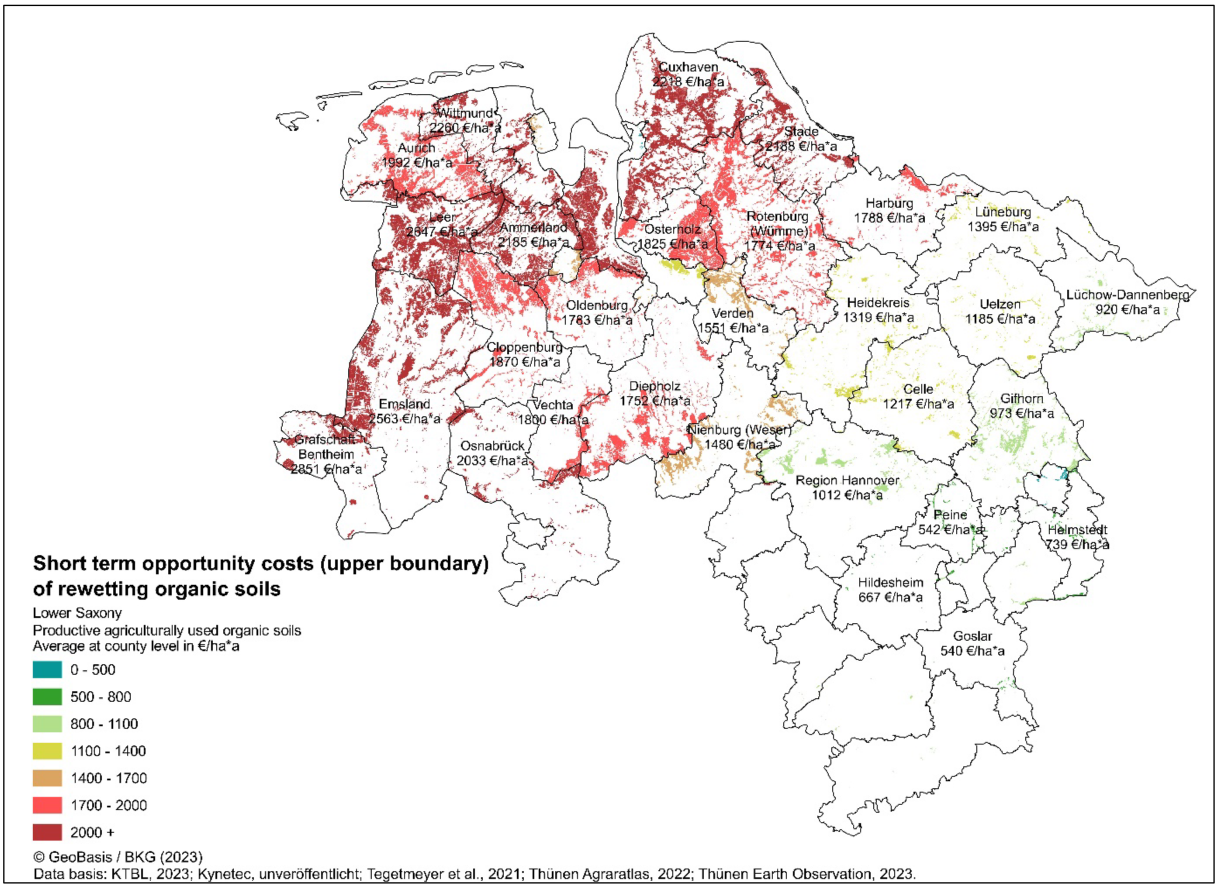
3.4 Total opportunity costs

The immediate rewetting of all agriculturally used organic soils would incur a total of between 740 million € and 1,6 billion € of short-term opportunity costs per year, depending on the necessary reductions in ruminant livestock. Annual long-term opportunity costs of about 325 million € are about half of the lower boundary of short-term opportunity costs and 20% of the upper boundary of short-term opportunity costs in Germany.

3.5 Regional differences

Differences in organic soil use and associated opportunity costs do not only occur between the federal states but also at higher spatial resolutions. The informative value of averages at the federal state level is therefore limited. Nevertheless, due to content limitations, we cannot present all of the regional differences here.

Figure 4: Short-term opportunity costs (upper boundary) of rewetting organic soils in the counties of Lower Saxony



Source: Own illustration and calculations, based on DILGER and FAULHABER, 2006; TEGETMEYER et al., 2021; THÜNEN AGRARATLAS, 2022; KTBL, 2023; THÜNEN EARTH OBSERVATION, 2023; KYNETEC, unpublished.
Remark: crop type aggregation: productive agricultural areas incl. special crops.

In Lower Saxony, for example, there is a (north-)west to southeast gradient in the proportion of organic soils in the total agricultural area as well as in the opportunity costs (Figure 4). Organic soils in the Northwest are characterized by intensive dairy cow husbandry, resulting in average short-term opportunity costs (upper boundary) between 1.700 and 2.650 €/ha*a. Lower livestock densities, as well as suckler cow husbandry, characterize the organic soil use in the Southeast. Accordingly, short-term opportunity costs (upper boundary) are substantially lower, varying between 500 and 1.000 €/ha*a. The cultivation of cereals, and especially potatoes, is an important form of organic soil use in the western counties of Lower Saxony (Grafschaft Bentheim, Emsland). Furthermore, calf and beef fattening are the dominant forms of ruminant husbandry dependent on forage from organic soils (Emsland, Cloppenburg). Accordingly, short-term opportunity costs (upper boundary) are high (1.850 – 2.850 €/ha*a).

There is also a gradient in opportunity costs in Schleswig-Holstein and Mecklenburg-Western Pomerania. While the decreasing ruminant livestock density from west to east is the reason for lower short-term opportunity costs in the eastern counties of Schleswig-Holstein, in Mecklenburg-Western Pomerania, it is a shift in the dominant ruminant types. In the western counties, dairy cows dominate the organic soil use, in the eastern counties suckler cows dominate.

4 Discussion

4.1 Opportunity costs and GHG mitigation potential

To contextualize the opportunity costs of rewetting organic soils, we relate them to the associated GHG mitigation potential given by Tiemeyer et al. (2020) and to GHG mitigation costs in other sectors. The European Union has established an European Emission Trading System (EU ETS), which limits GHG emissions from certain energy-intensive sectors. In 2023, the average EU ETS price was about 84 €/t CO2eq (UBA, 2024). In the federal states rich in organic soils, the short-term opportunity costs (upper boundary) of GHG mitigation through rewetting range from 20 to 68 €/t CO2eq (Table 2, Column 3) and are thus below the EU ETS price.

Table 2: GHG mitigation costs of rewetting productive agriculturally used organic soils

GHG mitigation costs Productive agricultural area incl. special crops	**Average short-term opportunity costs (upper boundary) in €/ha*a**	**Average GHG mitigation potential in t CO2eq/ha*a**	**Average GHG mitigation costs in €/t CO2eq**
Schleswig-Holstein	1.662	28,6	58,2
Lower Saxony	2.028	29,9	67,9
Bavaria	1.731	29,7	58,3
Brandenburg	578	28,6	20,2
Mecklenburg-Western Pomerania	768	27,4	28,0
Germany	**1.457**	**29,1**	**50,1**

Source: Own calculations based on DESTATIS, 2021b; DILGER and FAULHABER, 2006; KTBL, 2023; KYNETEC, unpublished; TEGETMEYER et al., 2021; THÜNEN AGRARATLAS, 2022; THÜNEN EARTH OBSERVATION, 2023; TIEMEYER et al., 2020.

The GHG mitigation costs given for rewetting organic soils (Table 2) omit the initial costs of rewetting, including the technical and administrative measures required to raise the water table, as well as the initial costs of implementing paludiculture, if applicable. Wichmann et al. (2022) provide a rough estimate for the initial costs of rewetting (4.000 €/ha) and the implementation of paludiculture (10.000 €/ha). Assuming a payback period of 30 years and an interest rate of 3% increases the GHG mitigation costs of rewetting by about 7 €/t CO2eq if the initial rewetting costs are considered. Implementing paludiculture increases the costs by about 18 €/t CO2 eq. This yields a range of GHG mitigation costs between 27 and 75 €/t CO2eq, including the initial costs of rewetting, and a range between 45 and 93 €/t CO2eq if the implementation of paludiculture is additionally included. Thus, if the implementation of paludiculture is included, the GHG mitigation costs of the federal states with the highest short-term opportunity costs slightly exceed the current EU ETS price. This price is expected to rise up to 130 – 160 €/t CO2eq, however, by 2030 (PAHLE et al., 2022). Furthermore, revenues from paludiculture potentially offset at least a part of the implementation and opportunity costs (SCHÄFER et al., 2022).

4.2 Short-term opportunity costs and compensating CAP second pillar interventions

The comparison with GHG abatement costs of EU ETS companies highlights the economic efficiency of rewetting organic soils. In contrast to realizable process changes in EU ETS companies, there are currently almost no profitable wet land use alternatives. In light of estimated economic welfare losses of 237 € per further ton of CO2 emitted (UBA, 2023b), this may justify governmental support for rewetting. In the latest revision of the CAP, four out of the five federal states rich in organic soils have introduced interventions for peatland protection measures intended to economically incentivize the rewetting of organic soils by compensating for the opportunity costs incurred (EL-0101-03). To assess their incentivizing effect, the subsidy rates of the interventions are compared with the average opportunity costs of rewetting (Table 3).

Since the second pillar interventions of the CAP are designed at the federal state level, the required management commitments, the subsidy rates, as well as the ability to combine different interventions vary (BMEL, 2023). All interventions related to organic soils require continued use of at least one annual mowing of the grown biomass. Mecklenburg-Western Pomerania and Brandenburg distinguish the subsidy rates of peatland protection measures according to the targeted water table. We focus on the highest possible target because we assume complete discontinuation of drained land use activities in our opportunity cost analysis. Where applicable, we consider the combination of interventions for the rewetting of organic soils with interventions for the extensification of permanent grassland since the rewetting of grassland necessarily comes at the expense of extensifying its use. If not indicated, interventions have a commitment period of five years.

Table 3: Average short-term opportunity costs of rewetting agriculturally used organic soils and compensating CAP second pillar interventions

Federal State	Intervention	Subsidy rate	Short-term opportunity costs: Lower boundary	Short-term opportunity costs: Upper boundary
Lower Saxony	**Permanent grassland**			
	Targeted minimal water table: 20 cm below surface,	536 €/ha		
	+ Sustainable use of permanent grassland	+ 453 €/ha		
	Sum	= **989 €/ha**	379 €/ha	1.644 €/ha
	Arable land			
	Targeted minimal water table: 20 cm below surface,	536 €/ha		
	+ Conversion of arable land to permanent grassland (7 years)	+ 2.569 €/ha		
	Sum	**= 3.105 €/ha**	1.070 €/ha	2.016 €/ha
Bavaria	**Permanent grassland**			
	Targeted minimal water table: 20 cm below surface (12 years)	900 €/ha + 125 €/ha		
	+ Sustainable use of permanent grassland	**= 1.025 €/ha**	481 €/ha	1.516 €/ha
	Sum			
	Arable land	**= 2.200 €/ha**	1.123 €/ha	1.692 €/ha
	Cultivation of paludiculture (12 years)	900 €/ha		
	OR targeted minimal water table: 20 cm below surface (12 y)	3.300 €/ha		
	+ Conversion of arable land to permanent grassland	**=2.275 €/ha**	1.123 €/ha	1.692 €/ha
	Sum (average over 12 years)			
Brandenburg	**Permanent grassland**			
	Targeted minimal water table: 10 cm below surface	199 €/ha		
	+ Targeted minimal water table in winter half-year: at surface	+ 48 €/ha		
	+ Sustainable use of permanent grassland	+ 165 €/ha		
	Sum	= **412 €/ha**	187 €/ha	492 €/ha
	Arable land			
	Cultivation of paludiculture			
	Sum	= **350 €/ha**	333 €/ha	647 €/ha
Mecklenburg-Western Pomerania	**Permanent grassland**			
	Targeted minimal water table: 10 cm below surface	450 €/ha		
	+ Sustainable use of permanent grassland	+ 190 €/ha		
	Sum	= **640 €/ha**	190 €/ha	659 €/ha
	Arable land			
	Targeted minimal water table: 10 cm below surface	450 €/ha		
	+ Cultivation of paludiculture	+ 450 €/ha		
	Sum	= **900 €/ha**	855 €/ha	1.266 €/ha
	OR Targeted minimal water table: 10 cm below surface	450 €/ha		
	+ Conversion of arable land to permanent grassland	+ 1.300 €/ha		
	Sum	**= 1.750€/ha**	855 €/ha	1.266 €/ha

Source interventions: Own composition based on BMEL, 2023; LM M-V, 2022; ML NIEDERSACHSEN, 2023; MLUK BRANDENBURG, 2023b; MLUK BRANDENBURG, 2023c; STMELF BAYERN, 2024.
Source opportunity costs: Own calculations based on DESTATIS, 2021b; DILGER and FAULHABER, 2006; KTBL, 2023; KYNETEC, unpublished; TEGETMEYER et al., 2021; THÜNEN AGRARATLAS, 2022; THÜNEN EARTH OBSERVATION, 2023. Remark: Crop type aggregations: permanent grassland, productive arable land excl. special crops.

All interventions compensate for at least the lower boundary of short-term opportunity costs, with a few even compensating for the upper boundary. However, the short duration of the interventions results in a low planning horizon, which remains a major obstacle (Nordt et al., 2022), that only Bavaria addresses with commitment periods of 12 years. Another obstacle is the subsidies paid for the drainage-based use of organic soils, which we have not considered in our analysis. Regarding the first pillar interventions of the CAP, it could be argued that these payments will continue even after a field is rewetted and, therefore, have no impact on our results (Regulation (EU) 2021/2115). In contrast, second pillar interventions subsidizing sustainability measures on drained organic soils may not be continuable in case of rewetting and therefore reduce the incentive effect of interventions for peatland protection measures.

In conclusion, the interventions that are already in place can provide a real incentive for rewetting if the commitment period is extended, if they are accompanied by sufficient programs to cover the initial costs of rewetting, and if counter-incentive subsidies are phased out. Additionally, funding for innovative land use alternatives, such as planted paludiculture, requires higher subsidies.

5 Conclusion and Outlook

With our analysis, we provide an overview of the diverse agricultural use of organic soils in Germany. Differences can be observed between federal states as well as the counties and municipalities within a federal state. Our land use analysis increases the accuracy of previous national organic soil use analyses because it captures differences in cultivation patterns at the field level. Nevertheless, uncertainties remain regarding the determination of ruminant livestock dependent on forage from organic soils. The inclusion of remote sensing data depicting the intensity of grassland use may address this issue (SCHWIEDER et al., 2022).

Based on the results of our land use analysis, we have derived the opportunity costs of discontinuing drainage-based agricultural activities on organic soils when rewetting them. From an economic efficiency perspective, it is advisable to rewet large parts of the organic soils because the average costs per ton of carbon dioxide equivalent mitigated are below or at most around the GHG mitigation costs of other sectors, e.g., EU ETS industries.

We provide a lower and an upper boundary of short-term opportunity costs. The range between both values is relatively wide. The range could be narrowed if the opportunities for adaptation in case of rewetting are further investigated. Since it seems to be impossible to conduct this at the farm level in national analyses, it might be a first step to analyze the relation between the proportion of organic soils in the total area farmed and the ability of farms to shift their production programs with the highest profitability to unaffected areas (KRIMLY et al., 2014).

Regarding rewetting premiums under the CAP, it’s unclear to what extent farmers will accept the new programs. Our analysis shows that the planned compensation payments are close to the average short-term opportunity costs calculated in this study. However, providing financial compensation is often not enough to accept a program. Other factors, such as the right of farmers to dispose of their land, legal aspects, and land owner structure, can hinder the success of these programs. These factors can lead to low uptake rates, as seen in the past for short rotation coppice. In addition, area-based payments with premiums determined at the federal state level are unlikely to reflect the heterogeneity of opportunity costs incurred in different regions of a federal state. They can lead to loss of effectiveness and generate windfall profits when predominantly the least productive organic soils, often characterized by comparatively high water tables, are rewetted. This lowers GHG mitigation and increases mitigation costs. In this context, premiums per ton of carbon dioxide equivalent mitigated could increase the economic efficiency of money spent (SCHÄFER et al., 2022). To apply such a system, an assessment framework is needed to determine the GHG mitigation potential of rewetting on a per-ton basis.

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