Climate Change Mitigation through Land Use on Rewetted Peatlands – Cross-Sectoral Spatial Planning for Paludiculture in Northeast Germany

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Abstract

Drainage of peatlands causes severe environmental damage, including high greenhouse gas emissions. Peatland rewetting substantially lowers these emissions. After rewetting, paludiculture (i.e. agriculture and forestry on wet peatlands) is a promising land use option. In Northeast Germany (291,361 ha of peatland) a multi-stakeholder discussion process about the implementation of paludiculture took place in 2016/2017. Currently, 57% of the peatland area is used for agriculture (7% as arable land, 50% as permanent grassland), causing greenhouse gas emissions of 4.5 Mt CO₂eq a⁻¹. By rewetting and implementing paludiculture, up to 3 Mt CO₂eq a⁻¹ from peat soils could be avoided. To safeguard interests of both nature conservation and agriculture, the different types of paludiculture were grouped into ‘cropping paludiculture’ and ‘permanent grassland paludiculture’. Based on land legislation and plans, a paludiculture land classification was developed. On 52% (85,468 ha) of the agriculturally used peatlands any type of paludiculture may be implemented. On 30% (49,929 ha), both cropping and permanent grassland paludiculture types are possible depending on administrative check. On 17% (28,827 ha), nature conservation restrictions allow only permanent grassland paludiculture. We recommend using this planning approach in all regions with high greenhouse gas emissions from drained peatlands to avoid land use conflicts.

Keywords Greenhouse gas emissions · Organic soils · Cropping paludiculture · Permanent grassland paludiculture · Eligibility map · Governance

† In honour of the late Dr. Uwe Lenschow and in memory of his achievements in rewetting peatlands in the federal state of MV.

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Introduction

Globally, less than 3% of the land area is peatland, but these lands store more carbon than all forest biomass in the world (Joosten 2009; Joosten et al. 2016a). Under natural conditions the enormous amounts of carbon stored in the peat are preserved by a lack of oxygen in water saturated conditions. When drained for agriculture, forestry or peat extraction, this fragile system quickly changes and the carbon stored in the peat over thousands of years is lost due to oxidative degradation (Joosten and Clarke 2002; Rydin and Jeglum 2013). This results in the release of enormous amounts of greenhouse gases (GHG). Depending on land use type and drainage intensity, between 17.25 (grassland, shallow drained) and 38.18 t CO₂ equivalents (eq) per ha and year (cropland) are emitted on average in temperate latitudes; under tropical climates, cropland emissions can reach up to 58.45 t CO₂eq per ha and year (Wilson et al. 2016 after IPCC 2014). Emissions

from drained peatlands and peat fires account for c. 2 Gt CO₂eq per year, which is equivalent to c. 5% of the total global anthropogenic emissions (Joosten et al. 2016a). In Germany, more than 90% of the peatlands are drained (Trepel et al. 2017). They account for 7% of the agriculturally used land and cause 37% of the agricultural GHG emissions (based on UBA 2019). In the northeastern federal state Mecklenburg-Vorpommern (MV) drained peatlands emit c. 6 Mt CO₂eq per year, being the largest single source of GHG emissions and thus a major challenge to deal with (LU MV 2009; GMC 2019a). Along with GHG emissions, peatland drainage also causes substantial nitrate leaching to surrounding waters (Tiemeyer and Kahle 2014), reduced groundwater storage and landscape cooling, increased flood risk, and loss of wetland biodiversity (Joosten et al. 2015).

The target to cut GHG emissions towards net zero CO₂ emission values by 2050 (IPCC 2018) implies that by 2050 all drained peatlands must have been rewetted (Abel et al. 2019). The type of land use plays a special role in this as it can both act as a source and a sink for GHGs (Smith et al. 2008). With continued drainage, 12–41% of the GHG emission budget still allowable for keeping global warming below +1.5 to +2 °C will be exhausted by peatland emissions (Leifeld et al. 2019). Growing awareness of the climate relevance of drained peatlands, and the range of problems and high costs associated with subsidence of organic soils, have already prompted action at national and regional levels. However, competition for land is globally increasing. To maintain the production function for rural livelihoods and to retain and restore wet grasslands as hotspots for biodiversity, a simple cessation of peatland use is no option. While current food production may be shifted to mineral soils, wet peatlands can provide biomass as feedstock and fuel which is increasingly demanded for mitigating carbon emissions from industry. As a consequence, a fundamental transition to ‘wet’ land use is inevitable.

Climate-friendly, wet peatland utilization is termed ‘paludiculture’, which implies that the production function of the land and simultaneously the peat body are preserved (Wichtmann and Joosten 2007; Wichtmann et al. 2010, 2016). In order to achieve a zero or slightly negative carbon balance in paludiculture, the water level has to be close to or above the surface throughout the year to guarantee water saturation of the peat body. In addition, regular soil disturbance, e.g. by ploughing or by harvesting below-ground biomass, is incompatible with peat preservation (Abel et al. 2013). Different types of paludiculture illustrate the combination of climate protection and peatland use (Joosten et al. 2012; Cris et al. 2014; Wichtmann et al. 2016; Joosten et al. 2016c; Gaudig et al. 2017).

By changing land use at large scale, land use conflicts can arise. The focus on the mitigation potential can result in far-reaching consequences in the landscape. The promotion of renewable energy in Germany, for

example, has led to a ‘biogas boom’ and a dramatic increase in maize cultivation (‘maizification’ of the landscape; Herbes et al. 2014; Rühs et al. 2016). This caused many undesired consequences, above all extremely high CO₂ emissions from peat soils drained for maize cultivation (Couwenberg 2007) and negative impacts on biodiversity. With regard to paludiculture, sown and planted reed beds which address production goals should be treated differently than natural reed beds, which are listed as protected habitats (Länder-Arbeitskreis Moorschutz and BfN 2017). Newly established reed beds can be an alternative in cases where traditional reed harvesting areas became designated as national parks and reed harvesters have lost the permission to cut Common Reed (Wichmann and Köbbing 2015).

To avoid undesired developments and, in particular, conflicts with the objectives of nature conservation, guidance is required on land eligibility and for implementing paludiculture. Collaborative processes are crucial as peatland management almost always concerns several land owners and land users (van Hardeveld 2019). As the first German federal state, MV has developed a technical strategy for the ‘Implementation of Paludiculture on Agricultural Land’ (LM MV 2017). This article describes the procedure of engaging stakeholders, creating a common knowledge base, defining land eligibility classes and thus developing an approach to facilitate shifting from draining peatlands towards climate change mitigation and paludiculture. In addition to guidance on the participatory planning procedure for rewetting and paludiculture, it also informs about risks and co-benefits, perspectives of spatial planning and funding framework, and transfer to other peatland-rich regions.

Approach to Stakeholder Involvement

The Ministry of Agriculture and Environment of MV decided to set up a consensus-oriented discussion process for the introduction and implementation of paludiculture in 2016. It implied personal invitations of representatives of agriculture, forestry, energy, nature conservation, water management, and sustainability from ministerial level, other state authorities (selected middle and lower levels), NGOs and academia, and convened a working group of 21 stakeholders over a period of two years. The group’s meetings emphasized exchange of knowledge on peatland management and explored the effects of land use and management changes on GHG emissions (cf. Brouns et al. 2015). The following issues have been discussed and agreement has been achieved on:

- a common understanding of the problem;
- a common knowledge base;
- solutions and a strategy for further procedures.

Generation of a Common Understanding and Knowledge Base

The working group accepted the need for peatland GHG emission reduction as indicated in the Paris Agreement (UNFCCC 2015) and the German Climate Protection Plan (BMUB 2016). The importance of peatlands for the production of food, fodder and renewable raw materials in MV was emphasized as well. The working group defined the goal to reduce the negative environmental effects of peatland drainage whilst continuing the production of agricultural goods. The group's members acknowledged the potential of paludiculture, stressing that carbon flow is addressed in three ways, safeguarding a zero or slightly negative carbon balance of the site (ABC principle; Fig. 1). They also underlined the necessity of economic viability and planning security for farmers. As a premise for land use change, the principle of voluntary participation was emphasized.

The group identified main topics to be reviewed jointly at the beginning of the discussion process and agreed on the methods to be used. First of all, a review of the current situation, starting with the distribution of peatlands, their use and importance for rural areas, climate protection, as well as nature, soil and water conservation, was compiled. The peatland map was based on the state's geological map supplemented by more recent data for coastal peatlands (LM MV 2017). The dataset also included shallow and former peatland sites which have a peat layer of <30 cm or an organic content of <30% as these sites emit, if drained, substantial amounts of CO₂ (Leiber-Sauheitl et al. 2014; Joosten et al. 2016b). Agricultural land within the overall peatland area was identified based on the agricultural field block cadaster. Peatlands in MV cover 291,361 ha (13% of the land area). The working group focused on those peatlands currently under agricultural use (165,880 ha, i.e. 57% of the total peatland area), including 20,531 ha of cropland and 143,998 ha of permanent grassland (Fig. 2, LM MV 2017). Possible land use restrictions were derived from datasets on protection status and occurrence of legally protected biotopes, habitats or species. In addition, expert landscape plans, information on protected landscape

components, and the grassland classes of the agri-environmental schemes were taken into account (Table 1). GHG emissions were assessed using the GEST (Greenhouse gas Emission Site Types) approach, which was developed in MV (LU MV 2009; Couwenberg et al. 2011) and is now used in globally applicable carbon credit schemes (e.g. Emmer and Couwenberg 2017).

Subsequently, the most up-to-date knowledge on paludiculture plants suitable for MV was compiled. Plants with a good potential to become established on rewetted peatlands in MV are Common Reed (*Phragmites australis*), sedges (*Carex* spp.), cattails (*Typha* spp.), Reed Canary Grass (*Phalaris arundinacea*), and Alder (*Alnus glutinosa*) (Abel et al. 2013; Table 2). Also animals such as Water Buffalo (*Bubalus bubalis*) can graze on wet peatlands dominated by reedbeds and sedges. The climatic conditions in Northeast Germany do not favor the large-scale cultivation of peat moss (*Sphagnum* spp.) and Sundew (*Drosera* spp.). In addition, the current legal framework and main obstacles that hamper the implementation of paludiculture into practice were described. Practical knowledge for some types of paludiculture exist in MV at minor scale, e.g. harvesting Common Reed for thatching (Wichmann and Köbbing 2015; Wichmann 2017), sedges/grasses for combustion, Alder for timber (both described in Wichtmann et al. 2016) and keeping Water Buffalos (Sweers et al. 2013, 2014). Except for Common Reed, all of them are accepted as agricultural or silvicultural practice. For other species such as cattails, knowledge from pilot sites exists (Oehmke and Abel 2016; Geurts et al. 2019), but field-scale implementation is just starting (10 ha in MV in 2019) and there is still uncertainty on practical farming aspects, biomass quality and profitability (Schröder et al. 2015).

Paludiculture Land Classification

Based on the common understanding and knowledge base, the group discussed possible solutions. In order to avoid economic failures, it is important to clearly communicate to land users that legal and planning requirements potentially result in

Fig. 1 ABC principle of carbon flow in paludiculture. Greenhouse gas emissions associated with peat soil drainage are Avoided, the carbon uptake is partly harvested and used as above-ground Biomass, and ideally atmospheric carbon is Captured and stored as newly formed peat

Fig. 2 Peatland use in Mecklenburg-Vorpommern, NE-Germany

restrictions in the choice of crops. Planning regulations relevant for implementing paludiculture were identified and analyzed. Based on existing restrictions, paludiculture eligibility classes were derived and presented in maps.

Restrictions predominantly exist with regard to modification of the existing vegetation structure. Therefore, the various paludiculture types were divided into two groups: ‘permanent grassland paludiculture’ and ‘cropping paludiculture’ (Table 2). The establishment of ‘permanent grassland paludiculture’ (wet meadows, wet pastures) can lead to a gradual change in species composition following increased water tables and management, but will usually not conflict with the nature protection objectives. Therefore, such shift in species composition would comply with existing legal or planning requirements and can possibly even benefit nature protection objectives. In ‘cropping paludiculture’, plants such as Alder, Common Reed, Cattail, Reed Canary Grass and other grasses are cultivated as target crop and replace the existing vegetation. On areas where the vegetation is subject to protection, replacement by paludiculture crops is not allowed. According to the regional nature conservation law (NatSchAG-MV), the following designations exclude a change of the existing vegetation structure: nature reserves, national parks, legally

protected biotopes, natural monuments, habitat types of the FFH directive.

Regarding these restrictions four paludiculture eligibility classes were developed (Table 1):

- Class 1: any paludiculture is possible
- Class 2: permanent grassland paludiculture is possible but cropping paludiculture only after an administrative check
- Class 3: only permanent grassland paludiculture is possible and an administrative check is needed to safeguard nature protection goals
- Ineligible: area is not eligible for paludiculture.

Class 1 includes all areas for which no nature conservation or planning restrictions exist and where thus all forms of paludiculture are possible. *Class 2* includes all areas in which ‘cropping paludiculture’ is not automatically excluded but where restrictions must be considered. A site-specific check by a relevant authority is needed and restrictions may arise. In Special Protection Areas (SPA, protected under the EU Birds Directive), for example, the suitability of areas for the protection of meadow birds or as resting areas must be maintained, and a

Table 1 Paludiculture classes with qualifying legal and planning restrictions and area sizes (from LM MV 2017; English names of protected area categories after BfN (2019))

Class 1 Any paludiculture possible	Class 2 ha Permanent grassland paludiculture or cropping paludiculture possible (with administrative check)	Class 3 ha Only permanent grassland paludiculture possible (with administrative check)	Ineligible ha	ha
Sum	85,468	Sum	Sum	Sum
Areas without restrictions	16,619	Biosphere reserves (transition zones)	1,431	Biosphere reserves (core areas)
Areas eligible for EAFRD funding: ‘low-intensity grassland’ (funding period 2014–2020)	68,849	Special Protection Areas (SPA): Natura 2000 habitat types (Habitats Directive Annex I; provisional map) Areas owned by nature conservation organisations	2,646	National park (core areas)
		12,753	10,674	Legally protected dryland and woodland biotopes
		1,268	9,732	
		Areas eligible for EAFRD funding: ‘valuable grassland habitats’ (funding period 2014–2020)	6,302	
		Natural monuments	357	
		Protected landscape elements	124	
		Areas with priority plant species (flora protection concept)	8,939	
		Expert landscape plan, class ‘wet biotopes’	7,813	
		Natura 2000 habitat types (Habitats Directive Annex I)*	2,093	
		Areas with Habitats Directive Annex II habitats	6,666	

Because of overlap between the single categories, area sizes do not add up to the total area of each class. Abbreviations: EAFRD = European Agricultural Fund for Rural Development (CAP second pillar).
* including presences of Annex II species and buffer areas

large-scale conversion into reed beds or forests can conflict with this goal. *Class 3* includes all areas that can be used as wet meadows/pastures, but not for targeted cultivation of paludiculture crops, as it would change the character of grassland. A site-specific check by a relevant authority is needed to safeguard nature protection goals. Especially species conservation aspects have to be taken into account as protected areas or habitats on dry peatlands which are rewetted for paludiculture may ‘deteriorate’. Compliance with legislation on biotope protection must be checked and the risk of undesired developments must be reduced. *Ineligible* areas are areas that are used for agriculture based on special permits in the core zones of biosphere reserves or national parks, or on which legally protected biotopes are designated that cannot be combined with paludiculture (secondary dryland biotopes, woodland biotopes).

The paludiculture land classification resulted in 85,468 ha (52%) where either permanent grassland paludiculture or cropping paludiculture can be established (class 1; Fig. 3, Table 1). For 49,929 ha (30%) an administrative check is required to determine whether cropping paludiculture is possible (class 2). Permanent grassland paludiculture can be additionally established on 28,827 ha (17%; class 3). A deviating use may be permitted in individual cases, but this requires more sophisticated planning and approval procedures (with uncertain outcomes).

Strategy for Climate Change Mitigation through Land Use on Rewetted Peatlands

Subsequently, the next steps and responsibilities to implement land use change on peatlands in MV were outlined. The conversion of the 20,531 ha drained peatland currently used as arable land into cropping paludiculture would yield an emission reduction of more than 0.5 Mt CO₂eq a⁻¹ (Table 3). By rewetting all peatlands assigned to class 3 (only permanent grassland paludiculture) and thus bringing most protected areas on peatland in a good hydrological condition, a similar amount could be avoided annually. Combining cropland transformation to cropping paludiculture and establishment of permanent grassland paludiculture on all other agriculturally used peatlands in MV, more than 3 Mt CO₂eq a⁻¹ (i.e. an amount equivalent to the total emissions of the transport sector in MV, GMC 2019a) could be avoided.

The need to change the current land use practice on peatlands was acknowledged by all members of the working group. Paludiculture can be a solution for reducing GHG emissions while continuing agricultural use. However, lack of experience and thus uncertainty on large-scale feasibility was highlighted. To tackle the challenge of future peatland use, the working group has expressed 12 recommendations. The discussion process should be continued by establishing a paludiculture working group at the state level (1). This group will formulate proposals for the abatement of constraints and for incentive instruments, in

Table 2 Paludiculture types and their potentials in Mecklenburg-Vorpommern on rewetted agricultural used land (after LM MV 2017)

Assessment of the potential of different paludiculture types on rewetted agricultural land										
	Wet pasture	Wet meadow	Cropping paludiculture					and other grasses		
			Black Alder	Reed	Reed	Canary Grass	Cattail	Peatmoss	Sundew	
										Permanent grassland paludiculture
State of development	x	x	x	(x)			(x)			
Implementation possible, ready for practical use	x	x								
Recognized as agricultural crop										
Demonstration site needed to show that ready for practical use										
Experimental site needed for further research in MV										
Suitable sites existing in MV	x	x	x	x	x					
Economically promising, as tested and/or demand/market existing	x	x	x	x	x					
Economic potential, revenues expected from material/medicinal use										
Favouring biodiversity (habitat value)	x	x	x	x	x					
Nature conservation	x	x	x	x	x					
Landscaping maintenance, protection of open/cultural landscapes	x	x	(x)	(x)	x					
Carbon store (peat preservation)	x	x	x	x	x					
Climate protection	(x)	x	x	x	x					
Carbon store and sink (peat preservation and formation)	(x)	x	x	x	x					
Obstacles	(x)	(x)	x	x	x					
Not unequivocally recognized as agricultural crop										
Difference to legal biotope protection ambiguous										
Impairment of objects of protection										
Soil	–	–	–	–	–					
Water	–	–	–	–	–					
Existing vegetation	–	–	(x)	(x)	(x)					

In brackets: only partly appropriate

particular for the next funding period of the EU's Common Agricultural Policy. A key element will be new agri-environment-climate measures focusing on water levels and mitigation of GHG emissions at peatland sites. Furthermore, demonstration projects (2) for cropping paludiculture with Common Reed and Cattail, but also for the processing of fresh biomass from permanent grassland paludiculture have to be established quickly. Already tested applications of paludiculture types like thermal utilization of biomass from wet grassland paludiculture and the cultivation of Alder must be put more widely into practice (3, 4). In order to accelerate implementation, cooperation between agriculture and forestry should be strengthened and suitable cultivation sites as well as local biomass and heat demands identified. The synergies in using biomass from landscape maintenance in protected sites has to be assessed by state authorities (5). In addition, the establishment of experimental areas for paludiculture research (6) and strengthening of peatland science and education (7) was stressed. Better guidance for farmers on peatlands (8) and an extension of the successful regional carbon crediting scheme 'MoorFutures®' that includes paludiculture (9) was recommended. Also the specifications for harvesting of natural reed beds should be revised (10) and data on the distribution and condition of peatlands has to be updated (11). Last but not least, a concept for increasing the acceptance of the upcoming land use change has to be developed (12). For each of the tasks, responsible entities were appointed.

Discussion

Paludiculture Risks and Co-Benefits

The discussion process implemented in MV in 2016/17 showed that a broad group of peatland stakeholders supports the concept of paludiculture and the need for its implementation (although no statement is made as to where paludiculture *has to* be implemented). While focusing the discussion on GHG emissions, production function and compliance with nature conservation, it is also important to reflect on alternative 'climate-smart' land use options on peatlands, and on risks and co-benefits of paludiculture not yet addressed in the planning process.

Alternative technical solutions to preserve the soil carbon store (= keeping C in; Fig. 1) include covering the peat soil with mineral substrates (e.g. sand or clay) or water management with subsurface drains. In both cases, it is not well proven that carbon stocks are thereby permanently secured and GHG emissions considerably reduced (Couwenberg 2018, Säurich et al. 2019, Tiemeyer et al. 2017, Weideveld et al. 2019). In addition, paludiculture offers the removal of carbon from the atmosphere by peat formation (= getting C in) along with preserving the soil carbon store (= keeping C in; Fig. 1). Therefore, it is more sustainable to direct efforts and investments towards establishing paludiculture.

Fig. 3 Paludiculture classes for agriculturally used peatlands in Mecklenburg-Vorpommern, NE-Germany. Class 1 = any paludiculture possible; Class 2 = permanent grassland paludiculture or cropping

paludiculture possible (with administrative check); Class 3 = only permanent grassland paludiculture possible (with administrative check)

Peatland rewetting to water tables close to soil surface effectively stops carbon dioxide (CO_2) emissions but can also re-establish the emission of methane (CH_4), especially in former agricultural peat soils with a significant input or presence of nutrients and dissolved organic carbon (DOC). Some crops, such as Cattail, perform better at water levels 5 to 20 cm above the surface, which may lead to substantial methane emissions (Couwenberg and Fritz 2012; Vroom et al. 2018; Geurts et al. 2019). Essentially, management must choose between CO_2 emissions from drained or CH_4 emissions from rewetted peatland. This choice must consider the radiative effects as well as the atmospheric lifetimes of both gases, with CO_2 being a weak but persistent and CH_4 a strong but short-lived greenhouse gas. As demonstrated by Günther et al. (2020), CH_4 radiative forcing does not undermine the climate change mitigation potential of peatland rewetting. Instead, postponing rewetting increases the long-term warming effect of continued CO_2 emissions. Therefore, economic interest in paludiculture accelerating rewetting progress would have an overall positive climate effect even in case of crops favouring slight inundation. Additionally, the targeted water management needed for

paludiculture can help fine-tuning water tables to highest climate benefits.

Paludiculture may also preserve or revitalize the regulatory functions of natural peatlands (Luthardt and Wichmann 2016). In particular, the mitigation of flood events should be highlighted. Although this can lead to decreased paludiculture harvests, cultivated crops and harvesting techniques are adapted to high water levels and thus able to recover quickly. The high water level also enables permanent cooling by evapotranspiration and increased humidity, which can contribute to climate change adaptation at local and regional level (Joosten et al. 2015; Wahren et al. 2016). Furthermore, paludiculture allows for more diverse and abundant characteristic mire biodiversity compared to the drained state (Joosten et al. 2016c; Närmann et al. 2019).

Perspectives and Challenges for Sectoral Spatial Planning

In order to avoid land use conflicts during the introduction of paludiculture, it is recommended to develop site-specific

Table 3 Scenarios for annual emission reductions by rewetting and conversion to paludiculture for peatlands in paludiculture eligibility classes 1–3

Scenario	Area [ha]	Emission factor [t CO ₂ eq ha ⁻¹ a ⁻¹]	Emission [t CO ₂ eq a ⁻¹]	Emission reduction [t CO ₂ eq a ⁻¹]
<i>Rewetting drained cropland</i>				535,859
Reference: drained, cropland	20,531	32.8	673,417	
Rewetting and cropping paludiculture	20,531	6.7	137,558	
<i>Rewetting drained grassland (class 3 only)</i>				507,356
Reference: drained, grassland	28,827	25.5	735,089	
Rewetting and permanent grassland paludiculture	28,827	7.9	227,733	
<i>Rewetting drained crop/grassland (classes 1 + 2 + 3)</i>				3,064,856
Reference: drained, cropland	20,531	32.8	673,417	
Reference: drained, grassland	143,693	25.5	3,664,172	
Rewetting and cropping paludiculture	20,531	6.7	137,558	
Rewetting and permanent grassland paludiculture	143,693	7.9	1,135,175	

Emission factors (after Couwenberg et al. 2011 and J. Couwenberg pers. comm.) for paludiculture are conservative and likely to be lower in practice

eligibility maps. In Germany, large areas are designated for preserving or restoring grassland, and therefore differentiating between permanent grassland paludiculture and cropping paludiculture is necessary in the spatial planning process. The paludiculture classes presented in this article can be further specified by including habitat requirements of paludiculture crops and economic potential. For example, nutrient demanding crops like Cattail (*Typha spec.*) should only be implemented where sufficient nutrient supply guarantees appropriate yields. Such an approach has been presented by Schlattmann and Rode (2019) for Common Reed and cattails in Lower Saxony (NW-Germany). Planning could integrate strategies to reduce the nutrient overload of streams and thus identify target areas for nutrient demanding cropping paludiculture. A planning approach for targeting GHG mitigation measures on organic soils has been developed in Finland based on peat depth and cultivation intensity (Kekkonen et al. 2019). Technological aspects as water availability, impact on neighbouring sites, access roads etc. cannot be covered by top-down planning but have to be addressed by site-specific feasibility studies and implementation planning.

In MV, it has not been clarified yet which authorities will have the main responsibility for dealing with applications for land use changes in rewetted peatlands. It is proposed that for areas in class 1 the Office for Agriculture reviews the planned land use change in the course of the application for EU direct payments. For areas in classes 2 and 3, administrative check and approval by the Nature Conservation Authority should be obligatory. The eligibility classes may also indicate whether implementation may be financed by agricultural and climate funds (class 1 and 2) or by funds focusing on biodiversity protection (class 3). It must also be emphasized that criteria for a permit to raise water levels under the Water Act have not been included in

the analysis and that obligations from the Water Authority must be taken into account.

Uncertainties regarding the paludiculture land classification result from the quality of the input data. On the one hand, this concerns the spatial distribution and condition of peatlands; individual areas may be missing from the maps or partial areas may have been incorrectly excluded or included. On the other hand, this concerns the input data for nature conservation, e.g. temporary planning specifications, such as areas for agri-environmental and climate schemes aimed at maintaining and promoting grassland, or changes due to the progressive mapping and improvement of Natura 2000 habitat types.

For the practitioner, ownership of the land and distance to the farm and/or processing facilities are of vital importance. A guided implementation of paludiculture should therefore be supported by governmental land swapping assistance schemes. As permanent grassland paludiculture is likely to be subject to further restrictions, e.g. regarding the type of use (grazing / mowing) and management dates (starting dates for grazing / mowing), it may be necessary to offer agri-environment-climate programmes as compensation.

Adjusting the Framework for Paludiculture

In Germany, as in many other countries, stands of Common Reed are legally protected. At the same time, Common Reed is a target species for cropping paludiculture. It may also develop spontaneously on rewetted, formerly agriculturally used land. Therefore, clarification at the legal level is required. According to the planning process presented in this paper, a clear distinction has to be made between natural (class 2 or 3) and planted reed beds (class 1 or 2) on former agriculturally used peatlands.

With regard to funding, appropriate climate measures, especially within the EU's Common Agricultural Policy

(CAP), must enable the land use sector to minimize its emissions (Wichmann 2018, Pe'er et al. 2019). The European Commission (2017) has declared environmental protection and the fight against climate change as one of the greatest challenges for the future CAP. The European Green Deal (European Commission 2019) calls for CAP measures such as eco-schemes to reward farmers for improved environmental and climate performance, including managing and storing carbon in the soil, and improved nutrient management to improve water quality and reduce emissions.

In MV, and in many other peatland-rich regions and countries, agriculture can achieve substantial climate benefits only by converting the currently agriculturally used peatland areas to paludiculture (GMC 2019b). Large-scale transition is only feasible if eligibility for CAP payments is secured for these peatland areas (Geurts et al. 2019; GMC 2019b). The main criterion should be the activity of rewetting peatland as well as the regular management of the peatland (vegetation), and not whether the plants used in paludiculture are listed as agricultural crops or not. Targeted agri-environment-climate measures are needed to make the novel agricultural activity (i.e. paludiculture) attractive, as it is still associated with many risks and uncertainties for farmers (Appulo et al. 2019, GMC 2019b).

Wider Application in Other Regions

The transformation of peatland use must take into account the different regional framework conditions, including current land use and socio-economy as well as the legal and planning status. The participatory planning procedure implemented in MV (LM MV 2017) and outlined in Fig. 4 is recommended for starting land use change towards paludiculture. In such a consensus-oriented stakeholder approach, first objectives have to be defined; a common understanding of the problem and a common information basis should be created, leading to jointly identified possible solutions. In the planning phase, existing regulations are analyzed, restrictions deduced, and

spatially explicit paludiculture classes developed. Once the planning has been worked out, measures can be taken to facilitate the practical transfer. This particularly requires demonstration projects in which the practicability is substantiated and knowledge gaps are closed. Obstacles restricting the transfer to practice should be identified and removed. Where appropriate, targeted incentives and funding instruments can be developed to stimulate implementation.

Paludiculture eligibility maps are currently prepared within a research project for three other peatland-rich German federal states (Schleswig-Holstein, Brandenburg, and Baden-Württemberg). Here, the similar eligibility classes as in MV are used, and also proportions of the classes within the respective total agricultural peatland area are similar (Närmann et al. 2019). In the Netherlands, local and regional ‘wet agriculture’ maps are emerging (e.g. T. Pelsma pers. comm.). The Interreg NWE project Carbon Connects aims to develop a peatland map for NW Europe that will be combined with data sets on land use and drainage level to estimate the opportunities for reducing GHG emissions by adopting carbon-friendly land use practices (J. Geurts pers. comm.). Recently, paludiculture land planning in the three Baltic States is being developed in a project of the European Climate Initiative. In Estonia, more than 600,000 ha have been identified as eligible for paludiculture (J. Ivanovs pers. comm.). Within the Interreg Baltic Sea Region project Desire (Wichtmann and Abramchuk 2019) these approaches are implemented on catchment scale for the river basin area of the river Neman (Lithuania, Belarus, Kaliningrad region and Poland).

Conclusion

The challenge of land use transformation on drained peatlands is enormous and will be accompanied by setbacks (Schröder et al. 2016). Reorganization of land use that has grown over hundreds of years requires a transdisciplinary approach and widespread sharing of experience from traditional dry land use

Fig. 4 Overview and timeline of the participatory planning procedure on peatland rewetting and implementation of paludiculture in MV, as an example for other regions

to innovative wet land use on peatlands. Ownership of stakeholders and transparency of the process is crucial. In one German federal state, a participatory procedure for the introduction and implementation of paludiculture at regional scale has been developed, mainly as a strategy to mitigate GHG. Its application will accelerate land use change towards paludiculture, which is necessary to meet the global and national targets in climate change mitigation and other environmental objectives. Newly established paludiculture classes justify on which peatlands permanent grassland paludiculture and cropping paludiculture can be established. It is important to note that no statement is made as to where paludiculture *has to* be implemented. This decision lies with the owners and farmers. The allocation of areas to one of the eligibility classes is not binding, but represents a planning and decision-making aid for farmers, their advisors, and the responsible authorities. The procedure allows to address regional particularities. To achieve net zero CO₂ emissions by 2050, it is strongly recommended to carry out similar coordinated procedures in other countries and regions with large areas of drained peatlands.

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