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GUIDELINES FOR IMPLEMENTATION OF PALUDICULTURE

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Picture front page: cattail crop (Tobias Dahms, AESA aerial)

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The original german version of the guide was developed in cooperation with the MoKli, MORGEN and Paludi-PRIMA projects. It is the culmination of experiences from pilot operations as well as consulting and research projects. As there is insufficient experience and literature on most aspects, this is therefore to be taken as an initial overview that cannot claim to be complete in all aspects. It covers the situation at the time of going to press in German (Aug/2022). Translation (except Chapter 5 and 6) from German to English was completed by ALM Translations in 2024. This was funded by a grant via the Paludiculture Exploration Fund from within the Nature for Climate Fund manged by Natural England. Chapter 5 and 6 have been updated and slightly adapted as part of the revision, especially information regarding the legal framework and financing options. However, there will be indications where developments are currently particularly dynamic or where updates and innovations can be expected. If possible, this guide will be revised in the future and hopefully supplemented with many new practical insights and tips - and will be reissued in a few years' time. The authors would be pleased to receive comments, feedback and reports on practical experiences with the guide.

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List of abbreviations

a	Year
ARGE	Working group
AECM	Agri-environmental and climate measures
AECS	Agri-environmental and climate schemes
BB	Brandenburg
BMBF	Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research)
BMEL	Bundesministerium für Ernährung und Landwirtschaft (Federal Ministry of Food and Agriculture)
BMUV	Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (Federal Ministry for Environment, Nature Conservation, Nuclear Safety and Consumer Protection)
BMWK	Bundesministerium für Wirtschaft und Klimaschutz (Federal Ministry for Economic Affairs and Climate Protection)
BNatSchG	Bundesnaturschutzgesetz (Federal Nature Conservation Act)
BY	Bavaria
CH_4	Methane
CO_2	Carbon dioxide
HCM	Harvest cubic metre
ERDF	European Regional Development Fund
EAFRD	European Agricultural Fund
EPS	Expanded polystyrene
CAP	Common Agricultural Policy
CAPDPR	Common Agricultural Policy Direct Payments Regulation
CAPCA	Common Agricultural Policy Conditionalities Act
CAPCR	Common Agricultural Policy Conditionalities Regulation
GAEC	Good agricultural and ecological condition
LU	Livestock unit
ha	Hectare
HMF	Hydroxymethylfurfural
HTC	Hydrothermal carbonisation
K	Kelvin
kg	Kilogram
LWaG	Landeswassergesetz (State Water Act)
m	Meters
M-V	Mecklenburg-Western Pomerania
N2O	Nitrous oxide
RRM	Renewable raw materials
LS	Lower Saxony
NSP	National strategic plan
NET	Negative emissions technology
PEF	Polyethylene furanoate
PET	Polyethylene terephthalate
PV	Photovoltaic
SW	Slaughter weight
S-H	Schleswig-Holstein
GHG	Greenhouse gas
DM	Dry matter
EIA	Environmental impact assessment
t	Ton
Scm	Stock cubic metres
WHG	Wasserhaushaltsgesetz (German Federal Water Act)
WFD	Wasserrahmenrichtlinie (Water Framework Directive)

1. Introduction

In Germany, around 75 % of the 1.8 million hectares of peatland and peaty soils (= organic soils) are in drainage-based agricultural use. These agriculturally utilised peat soils release enormous amounts of greenhouse gases (GHG) - a total of 41 million tonnes of CO_2-equivalents per year (UBA 2021). This corresponds to approx. 40 % of total GHG emissions from agriculture. In order to fulfil the 2015 Paris Climate Agreement, man-made CO_2-emissions must be reduced to net zero. For agriculturally utilised peatland sites, this means the reversal of drainage and restoration of water levels close to ground level. Climate neutrality in agriculture and land use will only be achievable with large-scale and rapid implementation of peatland rewetting for nature and climate protection and with the introduction of paludiculture. This represents an enormous challenge for farms operating on peat soils. Drainage was previously the main prerequisite for agricultural utilisation of peatlands and provided a reasonably reliable or even very good source of income for farmers. However, also wet peatlands managed via paludiculture can produce biomass yields and generate income.

However, the conversion and initially also the "rethinking" of farming in wet peatlands still presents many farmers with a major, if not "inconceivable" challenge. Implementation of paludiculture is currently still very much in the pilot stage. Many farmers are aware of the significant climate impact of their peatlands, but they lack specific practical knowledge for conversion alongside specific economic prospects and commercial exploitation partners. Some pioneering farms are already implementing cultivation at high water levels and paludicultures are being further developed and tested in research projects. However, large-scale realisation of such is still in its infancy.

1.1 Objectives and addressees of the guide

This guide is intended to provide guidance and support for the conversion of land and farms to paludiculture and is primarily aimed at farmers and owners of peatland who are considering or already planning a switch over to this effect. The aim of the guide is to summarise current knowledge and clearly present the individual steps. In particular, the guideline continues the work of Schulze et al. 2016 (DSS Torbos), Birr et al. 2021 (Steckbriefe für klimaschonende, biodiversitätsfördernde Bewirtschaftungsverfahren (Profiles for climate-friendly, biodiversity-promoting cultivation methods)) and the paludiculture book by Wichtmann et al. (2016). The guide is also aimed at other major players who play a decisive role in the implementation of paludiculture: project executors, water and soil associations, authorities, agricultural consultants, research institutions and potential utilisation companies.

This guide provides assistance for stakeholders who:

- want to maintain the agricultural use of peatland after raising water levels and are looking for information on how to do this,
- want to find suitable areas to carry out paludiculture,
- want to convert a farm to paludiculture or develop paludiculture as a branch of farming,
- identify new ways of utilising paludiculture biomass,
- want to utilise wet peatlands to cover their biomass requirements,

- improve other ecosystem services of managed peatlands (climate protection, water protection, climate adaptation, biodiversity).

Developments in the framework conditions for paludiculture are currently extremely dynamic and it is to be expected that said framework conditions, from agricultural policy and availability of specialised machinery to the marketing potential for products derived from paludiculture, will improve significantly over the next few years. The structure within the individual federal states will probably continue to vary greatly. The authors of the guide therefore recommend that every farmer or initiator discusses matters with the relevant authorities and inquires information about current state regulations for the respective federal state at the start of the project.

1.2 Notes on using the guide

The guide presents five areas of action which are relevant to the conversion to paludiculture in individual chapters (Overview in Fig. 1). The order of the chapters does not represent a compulsory sequence for implementation. Chapter 7 completes the guide by presenting three examples of implementation in Germany: Peat moss paludiculture on former bog grassland in Lower Saxony, cattail cultivation in rewetted fens in Mecklenburg-Western Pomerania as well as rewetting and extensive wet pasture management in the Swabian Donaumoos in Bavaria. For these three examples, detailed information is provided on the procedure, feasibility studies and authorisation procedures, as well as on site preparation.

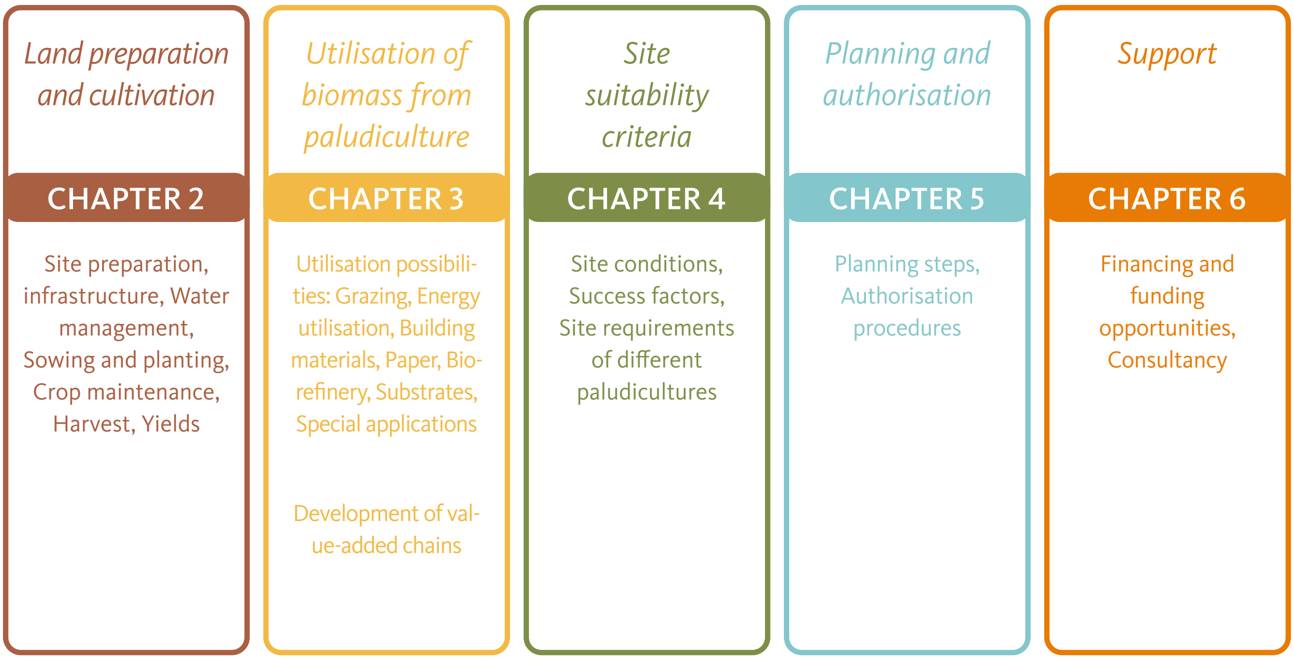


Fig. 1.1: The five areas of activity within paludiculture implementation and the contents of the chapter

Where to start?

You can start reading and using this guide with the appropriate chapter as well as skip individual chapters depending on your actual starting position and requirements. Here are a few examples:

- If owners or managers of peatland are unsure whether or how the conversion to paludiculture can succeed and what needs to be considered from an operational perspective, then it is advisable to start with the chapter on site preparation and management (Chapter 2).
- If owners or farmers have already decided to convert to paludiculture but remain unsure whether their land is suitable for it, or for which crops, then the chapter covering on-site suitability criteria (Chapter 4) may be helpful.
- If they are willing to convert and the suitability of land has been determined, but it remains unclear how the biomass obtained could be utilised and marketed, then start with the chapter on ways of utilisation (Chapter 3).
- Planning can begin immediately if the areas on which paludiculture will be practiced have been determined, as well as the utilisation channels or markets that are available. Essentially, the chapters on planning and authorisation as well as financing (Chapters 5 and 6) and the chapter on site preparation and management (Chapter 2) are recommended.

1.3 The paludiculture form of peatland management

Paludiculture is agricultural and forestry production on rewetted peat soils while preserving the peat body (LM M-V 2017a, Wichtmann et al. 2016). The name is derived from the Latin "palus" (= swamp) and was deliberately chosen as an analogy to other forms of land use such as horticulture, apiculture, agriculture or silviculture. However, paludiculture is not actually as new as its name, as wet peatlands have been cultivated since time immemorial – all over the world. In Germany, the use of reeds for roofing is one particular example, as is the litter utilisation of wet meadows. In other countries, for example, cranberry and papyrus harvesting from wet peatlands can be described as paludiculture. Nevertheless, paludiculture in Germany is also something completely new: peatlands that have been drained for decades and typically cultivated with water-intolerant plants are now being rewetted and cultivated with typical peatland plants. Use of the biomass obtained is also new and often innovative in many cases: the production of food takes a back seat, grazing only plays a marginal role – but on the other hand, the bioeconomy with the substitution of fossil raw materials in energy production and material flows (or cycles) is a key feature.

1.3.1 Forms of paludiculture

All paludicultures are permanent crops in which the above-ground biomass is utilised. Paludicultures can be differentiated according to the way they are established (see Fig. 1.2). The utilised growths can develop naturally depending on the water level and usage. For example, summer mowing or grazing creates wet meadows or wet pastures. Reed beds can be developed in a targeted manner by mowing in winter. Wet meadows or wet pastures usually consist of heterogeneous vegetation and are adapted to the site through their natural development. Crop paludiculture is the targeted cultivation of e.g. alders or reed plants such as reeds and cattails, which are sown or planted in pure culture. Grasses can also be sown in a targeted manner and, with appropriate management, can form stable vegetation levels over a longer period of time.

Furthermore, a distinction can be made between paludiculture on bog and fen soils. Despite major changes due to drainage and utilisation, they have different site conditions (e.g. nutrient availability) that become more pronounced over time, particularly after rewetting. These conditions limit the selection of cultivable plant species. Reeds, cattails, cultivated grasses and alder are primarily suitable for fen peatland sites, while peat moss or other special crops such as sundew or berries are suitable for bog sites. For more information on site requirements and plant selection, see Chapter 4.3.

The increased practical effort involved in the active establishment of crops is usually accompanied by increased administrative and organisational effort as special permits are sometimes required (see Chapter 5 "Planning and Approval"). There are also some differences in subsequent cultivation and management (see Chapter 2 "Site preparation and management" as well as the implementation examples noted in Chapter 7).

Fig. 1.2: Paludicultures can be wet meadows, wet pastures and deliberately established crops.

Converting peatland use and taking advantage of products together

There are currently very few opportunities to purchase biomass produced from paludiculture due to its limited availability. Establishment of new value-added chains requires a high, secure supply of raw materials and products from paludiculture. This can hardly be catered for at present because the switch from drainage-based to wet management is often time-consuming and costly. In addition, transport of voluminous raw materials has logistical limits and is cost-intensive. Conversion of land to paludiculture along with processing and marketing must therefore be thought through, developed and implemented together. This requires cooperative approaches along value chains and intermediary structures (DVL & GMC 2022). Wet meadows and wet pastures with heterogeneous stands can potentially cover a large area and therefore have great potential for biomass. Synergies with nature conservation are possible and they are cheaper to establish compared to crop paludicultures. On the other hand, crop paludicultures may potentially provide high-quality, specific raw materials due to their more homogeneous composition and therefore offer better revenue potential.

Establishment and (further) development of new production lines must be urgently accelerated. Social transfer payments for support are justified due to the positive side effects such as the reduction of climate-damaging emissions, mitigation of the consequences of climate change and the increase in added value within rural areas. Use of products from paludiculture can also be directly supported due to their low carbon footprint, e.g. in the construction sector and in horticulture. Alongside development and marketing of new products from paludiculture raw materials, there is great potential for feeding raw materials from paludiculture into existing production lines, e.g. the areas of paper production and moulded pulp.

1.3.2 Climate impact of paludiculture

The aim of paludiculture is to permanently preserve the peat body of the peatland as a basis for production ("peat-preserving utilisation") and thus to reduce GHG emissions as much as possible. In order to maintain the peat, water levels close to ground level are necessary all year round. From a climate protection perspective, this is also necessary in order to maximise the reduction of GHG emissions (Tiemeyer et al. 2020, Jurasinski et al. 2016). Cultivation at average summer water levels in the range of 10–45 cm below ground level is not paludiculture, but continues to consume peat and produce low to high carbon dioxide (CO_2) emissions (and nitrous oxide: N_2O emissions) (Tab. 1.1). The higher the water level within the peat, the lower the CO_2 emissions. The following applies: peat depletion takes place where CO_2 emissions occur. Higher CO_2 emissions mean higher peat depletion. Raising the water levels from highly peat-depleting to slightly peat-depleting cultivation can already lead to a significant reduction in GHG emissions. The distinction between strongly and weakly peatdepleting is based on an artificial boundary that was introduced for pragmatic reasons. This is based on the currently available GHG emission balances that have been measured, which may provide new findings as time goes on and may therefore also change the basis and the limits set in the future.

Paludiculture focusses on preservation of the peat body. Renewed peat formation is also possible under suitable conditions. Paludicultures are permanent crops in which only the above-ground biomass is utilised. Introduction of underground biomass (plant roots, rhizomes) can create new peat. However, there has been little scientific research on this to date, as there is a lack of long-term experience with paludiculture.

Different paludicultures and cultivation methods can lead to different site emissions, depending on site characteristics (Tab. 1.2). The reduction potential of the site's GHG emissions thus varies de-

Tab. 1.1: Delimitation and classification of water levels and climatic effects on peat depletion and peat preservation in utilised peatlands (after Närmann et al. 2021).

Management		Average water level within the peatland	**Emission ranges** in t CO_2 eq. per ha*a	Climate impact
peat-depleting	**strong**	Deep-drained peatland: summer water level more than 45 cm below ground level	~20 – 50	High to very high GHG emissions (especially CO_2)
	weak	Summer water level: approx. 10 to 45 cm below ground level	~5 – 20	Emissions were reduced where necessary, CO_2, N_2O and CH_4 emissions were also reduced.
peat-preserving (=paludiculture)		Water levels at ground level, slight water level fluctuations possible, overflow possible. Summer water level <10 cm[1] below ground level	~0 – 8	Maximum possible climate protection: minimum CO_2 emissions or CO_2 sink; CH_4 emissions occurring, increasing with overflow

1 Peat preservation may also be possible at an average of 20 cm below ground level, e.g. at sites with peat mosses, alder stands or coastal flooded peatlands. This is highly dependent on the trophic level of the site.

pending on the level of GHGs in the initial state and in the intended form of paludiculture.

Tab. 1.2: Overview of estimated site emissions from different peatland management methods. (Emission values from 1: Kaiser & Tanneberger 2021; 2: Daun et al. 2023; 3: Tiemeyer et al. 2020).

Paludiculture (reference)	Global Warming Potential (GWP) in t CO_2-eq. per ha*y
Reed [1]	~ 0 - 7
Cattail [1]	~ 6 - 7
Large sedge [1]	~ 3 - 10
Peat mosses [2]	~3
Wet pasture with water buffaloes [1]	~ 8 - 12
For comparison	
Grassland (on average) [3]	31,7
Arable land (on average)[3]	40,4

Like natural peatlands, peatlands cultivated in paludiculture can emit methane (CH_4) and a small quantity of CO_2. Particularly in the first few years after rewetting, during which the vegetation adapts to the new water level or is established through active measures, CH_4 emissions can initially rise sharply (Kaiser & Tanneberger 2021). However, the climatic effect of managed peatlands is primarily determined by CO_2, not CH_4. CH_4 initially has a stronger greenhouse effect than CO_2, but also disappears from the atmosphere relatively quickly. In contrast, CO_2 is steadily accumulating in the atmosphere. Both the extent of drainage and the timing of rewetting a peatland are decisive for the climatic effect for this reason. Peatlands must be rewetted as quickly as possible to prevent further global warming (Günther et al. 2020).

Products made out of renewable raw materials from paludiculture can even have two to three times the climate protection effect (Tanneberger et al. 2020, Nordt & Dahms 2021, Lahtinen et al. 2022):

1. Reduction in emissions due to the increased water level on the production area,
2. determination of carbon in the (durable) product,
3. and replacement of fossil raw materials, if applicable.

If this low or even negative carbon footprint were added to the product, this would lead to a market advantage and could raise demand for paludiculture raw materials.

In principle:

- **Paludiculture helps achieve climate protection goals.**
- **The highest climate protection effect and the lowest GHG emissions are achieved with water levels at ground level.**

1.3.3 Additional ecosystem services due to paludiculture

In addition to climate protection, paludiculture can have additional positive environmental effects when usage aims to preserve plenty of peat instead of consuming it. Wet peatlands fulfil important regulatory functions in the landscape water and nutrient balance and have an impact on local climate. These functions are largely lost during drainage. The irreversible damage to the peatland body makes it difficult to restore typical peat water levels. Permanent intervention is required in many cases, such as buffering strong water level fluctuations through targeted water management. This is also necessary for cultivation, so that paludiculture not only keeps water in the landscape and buffers weather extremes, but also supports the creation of natural functions. Implementation of wet farming methods can therefore also make an important contribution in adapting to climate change.

Nutrient retention: The peat body of drained peatlands is decomposed microbially. In addition to CO_2, nutrients are also released and enter the receiving water body with the drainage water. Rewetting minimises this nutrient pollution of water bodies in the majority of cases. At the same time, nutrient retention can take place through irrigation from nutrient-laden receiving water bodies. Harvesting the biomass, especially during summer mowing, removes nutrients from the system. Paludiculture can therefore make an active contribution to water protection (Holsten & Trepel 2016).

Water storage, buffer effect, flood protection: Wet peatlands have a direct impact on the water balance in the landscape. The retention of water in the peat body and the groundwater levels of the paludicultures close to the surface lead to a slower outflow of water from the peatland and from the landscape (Wahren et al. 2016). The quantification of additional groundwater recharge through rewetting requires a detailed hydrological study (Tiemeyer et al. 2017). In systematically drained regions, however, large areas of paludiculture can lead to an increase in the groundwater level in the surrounding landscape, depending on the type of hydrogenetic peatland. Greater water storage leads to less vulnerability in dry periods, which is particularly relevant for climate adaptation in regions with low precipitation such as north-eastern Germany. More information can be found in Wahren et al. (2016). If there is heavy rainfall or flooding, paludiculture areas can serve as retention sites as the adapted wetland plants tolerate waterlogging. At the same time, the runoff of precipitation is buffered (e.g. Ahmad et al. 2020). Paludiculture areas located along rivers can reduce the flow velocity, which is particularly relevant if there are areas downstream that represent a potential flood risk (Joosten et al. 2013, Wahren et al. 2016).

Cooling effects: The availability of water for evapotranspiration is high all year round and the sites act as local cooling and humidifying landscape elements with a more balanced annual temperature cycle (Wahren et al. 2016).

Biodiversity conservation: Rewetting leads to colonisation of typical peatland animal and plant species, including rare and endangered species (Närmann & Tanneberger 2021, Muster et al. 2015). Suitable quality habitats can be created or maintained through cultivation by mowing or grazing. Thermophilic and heliophilous species and open land types in particular benefit from the management of fens. In addition, cultivation encourages phytophages, which feed on the fresh growth. Conflicting objectives between climate and biodiversity protection can arise where rare dry habitats have become established on drained peatland sites that would be adversely affected by rewetting, or if the water level were to be raised in currently species-rich wet meadows (Närmann et al. 2021).

1.3.4 New job profiles in paludiculture

New job profiles will develop in various fields with the spread of paludiculture in Germany. From hydraulic engineering and agriculture to the various areas of paludiculture biomass processing (e.g. heating plant, production of building panels or furniture), there will be a need for specialisations focusing on peatland and paludiculture. However, the biggest changes and the biggest rethink will take place in the agricultural profession. Production of food on peatlands will increasingly fade into the background. Water buffalo and goose grazing on wet peatlands remain as niches in this sector. On the other hand, production of renewable raw materials for the management of wet peatlands is becoming increasingly important. However, farmers see themselves as producers of food and animal feed, and for more than 20 years also of renewable energy. For farmers in peatlands, production will expand to include climate protection in the future, which is why the Deutsche Verband für Landschaftspflege (German Association for Landcare) has developed the new job description of peatland climate manager.

Peatland climate managers are farmers who provide climate protection services through management of peatland soils. This climate protection service is provided by reducing or avoiding greenhouse gas emissions from the peat soils. This is achieved by raising the water level to at least slightly peat-depleting conditions or by restoring or maintaining high water levels that are typical of a peatland. The production of climate protection on peatland is to become a new line of business for farms with peatland. This can be realised in the future with or without making use of what is grown. Converting or adapting a farm means the farmer has to rethink their operations. The occupational profile of the peatland climate manager is intended to combine this with their existing self-perception as producers. Examples of such farms are presented in detail in the DVL brochure "Moor-Klimawirte – Zukunft der Landwirtschaft im Moor" (Peatland climate managers – the future of agriculture on peatlands)[2].

2 more information: www.moorklimawirt.de

2. Site preparation and management

This chapter summarises information that is helpful for successful site preparation and management. Various examples of paludicultures are used to describe site establishment, site preparation, sowing and planting, water management, crop care and harvesting as well as possible yields.

It is necessary to raise water levels for all forms of paludiculture on previously drained sites. There are many years of experience with rewetting within the realm of nature conservation, so successful rewetting requires good planning, knowledge of the area and hydrology as well as accompanying monitoring (see Chapters 4 and 5). Information on rewetting with a focus on nature restauration is summarised in the listed (mostly german) guidelines:

- Leitfaden der Hochmoorrenaturierung in Bayern (2002)
- Leitfaden der Niedermoorrenaturierung in Bayern (2005)
- Leitfaden zur Renaturierung von Feuchtgebieten in Brandenburg (2004)
- Praktischer Moorschutz im Naturpark Erzgebirge/Vogtland und Beispiele aus anderen Gebirgsregionen: Methoden, Probleme, Ausblick. (2007)
- LIFE Moore in Rheinland-Pfalz - Leitfaden zur Wiedervernässung. Stiftung Natur und Umwelt Rheinland-Pfalz (2011)
- Praktische Hinweise zur optimalen Wiedervernässung von Torfabbauflächen (2004)
- Global Peatland Restoration Manual (2008)
- DSS-WAMOS: Eine 'Decision Support System' - gestützte Managementstrategie für Waldmoore (2009)
- Global guidelines for peatland rewetting and restoration (2021)

However, rewetting for nature conservation is often aimed at minimising ongoing costs and interventions. Measures that only allow passive water management predominate for this reason. Water level fluctuations are the result of the irreversibly damaged peat body. However, more measures must be taken in paludiculture to mitigate water level fluctuations and enable active water management (Wichtmann & Schröder 2016). The following chapter provides specific information on irrigation and water management for paludiculture.

2.1 Preliminary considerations for agricultural businesses

The conversion to paludiculture potentially entails far-reaching operational restructuring and cultivation of wetlands places new demands on farmers. The most important factors affecting the profitability of paludiculture on farms are:

- the initial situation on the farm and on the land,
- establishment, land management, harvesting, utilisation and marketing costs,
- the revenues to be generated from commercialisation of paludiculture products,
- the level of remuneration for ecological services and
- the agricultural policy framework.

Information on potential revenues for raw materials and products from paludiculture can be found in Chapter 3, Table 3.10. Possible costs of paludiculture implementation are described in Chapter 2.3. Current obstacles to the implementation of paludiculture include current agricultural and structural support as well as other legal framework conditions, operational aspects, water availability and management, reservations on the part of farmers, landowners and residents, the need for financing and limited experience in utilisation (Nordt et al. 2022).

Operational structure and equipment

The initial situation of a company is determined by company-specific factors such as the previous company structure, the equipment and utilisation of said equipment (sites, machinery, workforce, etc.). Investment and funding requirements as well as necessary organisational changes can be estimated and an operational concept for economic wet peatland management and utilisation can be developed based on this. The following questions can help with this:

- Are existing sites suitable for paludiculture (see Chapter 4)? Where are these sites located within a peatland body or area? Do areas have to be swapped or rounded off? Special attention must be paid to hydrological conditions (if necessary, consideration in hydrological feasibility studies). Contact must be made with the farmers of suitable sites, e.g. adjacent areas, for this purpose.
- Are there operating sites or potentially leasable areas within a project area for rewetting?
- How large is the area and how much harvest has to be integrated into a material flow?
- Are there already ways of utilising peatland growth on the farm or in the region? What are the raw material requirements for the biomass resulting from utilisation and can these requirements be achieved on the land?
- Would additional technology and infrastructure be required on the farm for harvesting and storing, and possibly also for drying or compressing the biomass (see Chapter 3)?
- Is adapted technology available for planned paludiculture? If not, what type of technology is required (see Chapter 2.3)? Can this be jointly procured and used in cooperation with other farmers? Can machinery be hired regionally or are there local contractors with the appropriate technology?
- If no utilisation routes are available, are there any processing companies or suitable production sites for expanding or initiating regional processing? Are there already contacts with companies with similar raw materials (see Chapter 3)?
- Which subsidies or funding will remain in place after the changeover, and which will be cancelled or added as a result of the changes in operation (see Chapter 6)?
- Which production factors are present within the company and to what extent are they used?
- What are the investment requirements (depending on the type of paludiculture that is envisaged)?
- Are there any earmarking periods for current loans or subsidies that must be included in the schedule for the changeover process?
- How can expertise on wetland management be acquired? Is there a need for consultancy, who advises on this? Where are suitable further training programmes available (see Chapter 6.2)?

External help can provide support in answering these questions and developing a concept for operational conversion and management. Possible contacts are Landschaftspflegeverbände (landscape conservation associations),[3] Lokale Aktion groups and other agricultural advisory services within German federal states (see also Chapter 6).

Area selection and realisation / Target crops and their requirements: The possible yield potential of the site in relation to the target crop plays a central role in making paludiculture economically viable. Requirements of the desired paludiculture (wet meadows or crop paludiculture, specific species) provide a starting point (see Chapter 2.2). The steps required to set up and cultivate a paludiculture area vary depending on the crop.

Management scenarios: The yield capacity of paludiculture is primarily determined by the water levels and nutrient supply. The results of hydrological modelling and feasibility studies (see Chapter 4; examples in Chapters 7.1 and 7.2) should therefore be used to examine various scenarios (e.g. caused by water level fluctuations due to floods, low water, dry summers) from an operational perspective, e.g. along the following lines: What do the scenarios mean for cultivation and management? Where can water management be used and where not? Is additional water available? This is followed by practical questions: How is a power supply possible for any necessary pump operation? Possible changes in management and fluctuations in yield, e.g. due to flooding or drought, should be considered from the outset and preventive measures should be developed.

2.2 Specific site preparation and set-up, management

2.2.1 Infrastructure and site preparation

In principle, existing agricultural and water management infrastructure can be used to establish paludicultures. From a technical perspective, the condition and structure of the ditch and drainage systems in the area and the wider neighbourhood are of paramount importance for the ability of the site to be wetted. It may be necessary to reconstruct or optimise **hydraulic engineering facilities** (dams, pumping stations, irrigation ditches, spillways) (Fig. 2.1., 2.2). An **energy source** may also be required to operate pumps. This means that access to water, such as an adjacent receiving watercourse, is advantageous for the extraction of water. Furthermore, these areas must be accessible via **access roads** for (harvest) machinery and biomass removal. It should be borne in mind that in the case of high-growth paludicultures such as reeds or cattails, even a high biomass volume usually requires only one harvesting date and that this may require an expansion of the road infrastructure to the area and/or the access roads, as well as nearby transfer points for the harvested material. Multiple crossings should be avoided in order to protect the sward (Schröder et al. 2015, Wichtmann & Schröder 2016).

3 See www.moorwissen.de/mokli.html or www.moorklimawirt.de

Fig. 2.1: Embankment as a boundary for a cattail culture, which has an outer ditch in front of it to the still drained grassland (right edge of the picture). Photo: T. Dahms, 2020). The embankment has a 3 metre wide crown and driveways with flattened banks in several places. The embankment is regularly mowed and the electric fence erected on the embankment to keep out wild boar is also regularly cleared of vegetation.

Abb. 2.2: Left: Artificial pond and pump for irrigation, and a monk (spillway) for regulating the water level in a cattail culture can be seen at the front of the picture. Right: Pressure pipe outlet on the inside of the area and solar modules in the background for operating the solar pump (photos: J. Neubert, 2022; see also Chapter 7.1). Adjustable weirs, pumps (mobile or stationary) including energy supply (solar modules, wind turbine, diesel generator or power connection) are required to control the water level.

The following measures can be used to improve infrastructure both inside and outside the harvesting areas (according to Wichtmann & Schröder 2016):

- Construction of paved transport routes and transfer points,
- Adaptation of existing transport routes to high water levels, if necessary upgrading or building new bridges,
- Improvement of accessibility of the area by filling in the ditch and rounding off,
- Creation of additional access roads,
- Regular upkeep and maintenance of the infrastructure,
- including use of mobile road plates on access roads if required.

Paludicultures are permanent crops. There is no regular treatment of the topsoil. However, one-off tillage may be necessary when establishing a paludiculture area. Repetition may be necessary if the establishment has failed or if a change of target species or renewal of the stock is necessary. Tillage serves to establish the crop, prepare the seedbed and reduce competition from weeds during the establishment phase. Experience from grassland renewal (e.g. slit sowing) and initial afforestation on grassland (e.g. strip tiller) can be used and further developed for this purpose. For example, forestry planting machines can be used for planting paludicultures before irrigation begins (Fig. 2.3).

Minor topsoil removal may be necessary to level peatland areas or to obtain soil material for the construction of dams or filling in drainage ditches. At the same time, the degraded topsoil is removed and can thus favour the establishment of a crop paludiculture (e.g. relevant for peat moss paludiculture).


Fig. 2.3: Mechanical planting of cattail with a forestry planting machine (Photos: left T. Dahms, right A. Nordt, 2019). If planting is carried out before waterlogging, i.e. while the soil is still drained, the planting machine technology can be transported to the site using standard transport technology and there are no special infrastructure requirements.

2.2.2 Water retention and water management

Hydraulic engineering measures for water retention as well as for irrigation and, if necessary, drainage ensure that water levels that preserve peat as far as possible are maintained throughout the year. Water retention can be achieved, for example, by closing ditches, installing (adjustable) dams (e.g. Kratz & Pfadenhauer 2001), as well as by creating nearby water reservoirs[4]. Hydraulic engineering measures for establishing a paludiculture area on previously drained land require continuous intervention in the water balance in many cases. This conditional "artificiality" serves to restore water levels close to ground level. Structures such as dams are necessary in many cases, allowing targeted regulation of water levels. As well as water retention, irrigation with additional water may also be necessary (LM M-V 2017a).

The water management to be realised depends on the availability and quality of water, the site conditions, the degree of degradation and the requirements of the crop (see Chapter 4.1). In order to restore peat-preserving water levels, it is primarily necessary to examine the extent to which this can be achieved with one-off measures, such as the removal or filling in of drainage ditches, the installation of low weirs and jam flaps or the construction of dams. The main purpose of these measures is to keep water in the area. They offer few options to control the water level in a targeted manner (Wichtmann & Schröder 2016). Only a strongly fluctuating water level can be achieved in most cases.

Optimal water levels for paludiculture often require further measures (Wichtmann & Schröder 2016). The altered pore structure of the soil has also changed the water conductivity, leading to limited water movement from the ditches into the area by means of ditch damming (Luthardt & Zeitz 2018), so that even when the ditch water level is high, the water levels in the area drop low due to summer evaporation. It is only possible to limit the drop in water levels in summer by retaining excess water from the winter months. Water levels of more than 1 metre below ground level are still possible (e.g. Limberg 2022). This deep subsidence can be reduced by a high overflow of winter water, for which peatlands with underlying gyttja substrates or with impounding mineral soil substrates underneath the peat are particularly suitable (Wahren et al. 2016, Wahren 2016; Landgraf 2018). The higher the water and therefore the longer the stored winter water can be held into the summer, the longer the water levels can be prevented from falling (Fig. 2.4). The pores in the peat can store much less water compared to the overflow, which explains the rapid drop after sinking below ground level. If sufficient additional water is available, additional seasonal demand can also be compensated for by summer watering via ditch overflow. If the soil surface is significantly below the level of the receiving water body due to the drop in height of the peat body then the water can be supplied via free inflow (Wichtmann & Schröder 2016). The construction of new irrigation ditches may also be necessary to optimise distribution of water across the area. Due to the limited hydraulic conductivity of the degraded peat, additional water can only be brought into the area by periodic overflow (Limberg 2022). Target water levels can be documented and checked using suitable measuring points at weirs, dams, pumping stations or gauges. However, this is not possible in areas with water abstraction bans in summer.

Restoring the free inflow reduces costs for permanent operation of water control facilities. Furthermore, regular flooding allows nutrients to be replenished, but can also lead to nutrient discharge in the event of prolonged flooding (see Chapter

4 e.g. implemented for peat moss paludiculture in western Mecklenburg

2.2.3). The water levels of areas with free receiving water situations are subject to natural fluctuations in the water levels of the receiving water body. This can restrict cultivation, for example due to overflow at harvest time, or lead to water levels far below 20 cm below ground level (LM M-V 2017a), which may reduce or increase productivity (depending on the vegetation) and lead to peat depletion.

Outside of the raised bog regions, peat-preserving water levels can only be achieved by watering with periodic summer overflow or by high overflow using excess water from the winter months (Fig. 2.4, Wahren 2016). However, the latter can severely restrict the ability to cultivate. In addition, narrow cascades and further division of these areas by dams are required for sufficient water retention. Otherwise, peat-preserving water levels in the peripheral areas of the peatland complexes can only be achieved by permanent overflow and abandonment of the low-lying areas.

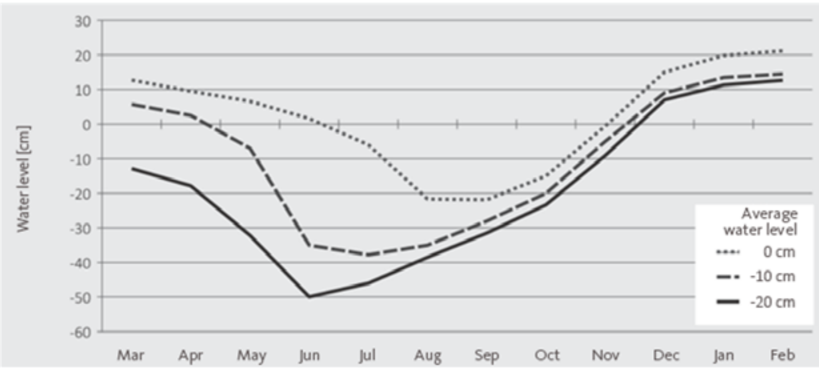


Fig. 2.4: Modelled water level hydrographs for different initial water levels of a peatland in north-eastern Germany (Wahren 2016). With an annual average water level that is at ground level, the water levels are up to 20 cm above ground level in winter and 20 cm below it in summer. An average water level of 20 cm below ground level means that the water level is 10 cm above ground level in winter, is lowered below ground level in spring and thus drops to up to 50 cm below ground level during the vegetation period.

2.2.3 Nutrient management

Many nutrients have accumulated in the topsoil in drained peatlands due to peat mineralisation and fertilisation, so that after rewetting there is an increased risk of nutrients being discharged into the receiving water bodies (Zak & Gelbrecht 2007). Phosphorus deposited in drained peatland can be mobilised again during rewetting. Various studies show that the increase in phosphorus re-dissolution within rewetted peatlands that have been drained and fertilised in the past represents a serious water quality problem if they have an unfavourable iron-to-phosphorus ratio (Land et al. 2016, Zak et al. 2014, Audet et al. 2020, Negassa et al. 2020, Walton et al. 2020). Nitrogen (N) is continuously replenished by atmospheric deposition (approx. 12 kg in M-V to over 30 kg of N per ha*a in Lower Saxony[5]). A further nutrient input occurs laterally from the (agriculturally) used environment through surface and groundwater inflow into the peatland body (Hinzke et al. 2021). Nutrient enrichment in the topsoil ensures a high availability of nitrogen and phosphorus in the first few years after land use change (Emsens et al. 2017). However, for example, the supply of potassium is more problematic. Even with a sufficient supply of nitrogen and phosphorus, an unbalanced nutrient ratio can lead to a decline in yield (Vroom et al. 2022, Geurts et al. 2020). In addition, nutrient replenishment resulting from peat depletion is discontinued due to the higher water levels. This leads to gradual impoverishment of the sites, especially when used in summer.

Targeted water management can support the supply of nutrients to the site whilst simultaneously reducing the input of nutrients into downstream water bodies. In particular, nutrient-laden receiving water bodies can be used for irrigation and for additional nutrient supply, provided that the paludiculture in question requires plenty of nutrients.

5 https://gis.uba.de/website/depo1/

The overflow should be as extensive as possible to ensure an even supply of nutrients. Otherwise, nitrogen in particular will be completely denitrified by the root filter within a short distance. Samples should be taken regularly from both inflows and outflows to realise the ideal flow rates/retention times and to prevent nutrients from dissolving back out of the soil (if retention times are too long) (Lenz 2001).

Harvesting paludicultures removes nutrients from the site depending on the harvest date. The earlier the harvest, the more nutrients are exported with the harvested material (Geurts et al. 2020). At later harvest dates, parts of the nutrients bound in the above-ground biomass were already transferred to the roots and rhizomes or leached out by precipitation.

The biomass yield of cattail (T. latifolia) and reed (P. australis) increases with higher nutrient availability, with nitrogen in particular being the limiting nutrient (Geurts et al. 2020). While cattail has a higher nutrient uptake capacity, reed has a higher nutrient efficiency and reacts less markedly to reduced nutrient levels. With a (medium-term) decline in the availability of nitrogen, potassium and phosphorus, reeds can therefore be expected to produce more stable yields in the long term (Geurts et al. 2020).

The biomass yields on a long-term wet meadow with summer mowing in Mecklenburg-Western Pomerania varied between 3 - 6 t DM per ha* a (Wenzel et al. 2022).

Depending on the location, time of harvest and quality of the irrigation water, impoverishment effects can occur, which can significantly reduce the productivity of the site (Oehmke & Abel 2016). The supply of elements that are lacking, e.g. via irrigation water, especially in the case of temporary waterlogging (Wenzel et al. 2022) can promote the capacity for phosphorus and nitrogen uptake by plants and thus increase nutrient retention potential. There is a need for research, particularly on potential effects of the provision of stored water through the discharge of larger artificial receiving waters into these areas. There is no experience to date with the use of soil additives on paludiculture areas.

According to current legislation, fertilisation is not permitted in waterlogged soil (Fertiliser Ordinance DüV 2017[6]). This includes all paludiculture areas, as the groundwater table distance here is a maximum of 20 cm below ground level, meaning that waterlogged soil conditions exist all year round. There is a need for research into whether and under what conditions fertiliser can be added to paludicultures in an environmentally friendly manner.

Peat mosses naturally grow in nutrient-poor habitats. Their cultivation under nutrient-rich conditions is associated with the increased growth of vascular plants, which must be mowed regularly so as not to substantially reduce the growth of peat moss. If this is ensured, peat moss can grow very well even under nutrient-rich conditions, but this can lead to the promotion of species other than the target species. It is therefore preferable to irrigate with nutrient-poor water. Setting up planted filter beds and using the filtered water for irrigation may be a solution (see Chapter 7.2).

2.2.4 Crop paludicultures

This subchapter summarises information on the establishment of various paludiculture crops along with specific information on cultivation, which is already relevant for preliminary considerations and decisions on the selection of a crop. This is subdivided into:

6 https://www.gesetze-im-internet.de/d_v_2017/BJNR130510017.html

- Cultivated stalks (reeds, cattails, reed canary grass, sedges),
- Peat moss paludiculture,
- Black alder.

Additional literature references and web links are provided for more detailed information on crop control and management. In addition, Chapters 7.1 and 7.2 present specific examples in detail regarding implementation of a peat moss paludiculture near Oldenburg and a cattail culture near Neukalen, both in northern Germany.

Crop stalk paludicultures

Experience of creating sedge meadows with and without removing the sward was already gathered in the 1990s in the Friedländer Große Wiese and Rhinluch wetlands of north-eastern Germany (Roth et al. 2001). In the MoorUse project in Bavaria, sowing reed canary grass (Phalaris arundinacea) worked without any issues, while planting sedges (Carex spec.) was more promising (both with intensive weed control) (preliminary results, personal notice, Tim Eickenscheidt, October 2019). The Moor-KULAP research and innovation project[7] involves development, testing and optimisation of quality seed mixtures consisting of moisture-tolerant grasses and herbs for Bavarian fen sites and the testing of reseeding with moisture-tolerant species.

Fig. 2.5: Bird deterrence in a cattail paludiculture in M-V (see Chapter 7.1). Four inflatable pool animals in bright colours were attached to poles across the area to deter geese. A so-called 'turbo ball' was also installed to deter swans.
Photo: S. Wichmann, 2020.

7 https://www.lfl.bayern.de/iab/kulturlandschaft/240564/index.php

Box 2.1 Overview of measures for the establishment and maintenance of crop stalk paludicultures

Crop stalk paludicultures, e.g.
reed (*Phragmites australis*), **cattail (***Typha spp.*), **reed canary grass** (*Phalaris arundinacea*)
(see also the implementation example for "Cattail cultivation" in Chapter 7.1)

Site preparation	• Water retention: Closing ditches, dams, possible capping of old drainage pipes • Backfilling of embankments/dikes/driveways/additional access roads • If applicable, terracing of undulating terrain • Infrastructure for water management, hydraulic engineering measures if necessary
Water management	• Water withdrawal from the receiving water body for irrigation: Adjustable inlet with free inflow, artificial pond or pump shaft, creation of ditches/ridges for irrigation, laying of pipelines, installation of adjustable overflows and cascades • Active irrigation by pumping requires an energy source either via the power grid or from a decentralised source (solar, wind energy)
Crop establishment, sowing and planting	• If applicable, ploughing, harrowing, cultivating, tilling the sward • Seeding: not suitable for reeds, for cattail only on flat areas with prepared (pelleted) seed due to the risk of drift; suitable seed mixtures are still being developed for wet sites (e.g. LfL Bayern), regional origins from comparable sites can be used after testing the quality parameters • Sowing density of reed canary grass 15 - 25 kg per ha with row spacing of 12.5 cm • Planting: Seedlings by hand or mechanically using forestry or vegetable planting machines • Planting density of reeds 0.25 - 4 plants per m², cattail < 2 seedlings per m² • Deterring geese and wild boar (Fig. 2.5)
Area maintenance	• Mowing of embankments, once or several times a year • Maintenance cuts when establishing stock • Control and maintenance of water management infrastructure
Harvest	• Annual harvest (establishment period 1-3 years) • (track-based) special technology, harvesting of chaff, bales, bundles • Seigas (technology with large balloon tyres) are also established, particularly for reed harvesting for thatching • In the future: autonomous light equipment carriers
Yield	• Reed: 6-24 t DM per ha* a, in winter 3-15 t DM per ha* a • Cattail: 4-22 tonnes DM per ha* a • Reed canary grass: 1.6-13 tonnes DM per ha* a
Sources and further information	• Birr et al. (2021): Zukunftsfähige Land- und Forstwirtschaft auf Niedermooren. Steckbriefe für klimaschonende, biodiversitätsfördernde Bewirtschaftungsverfahren • Overviews of paludiculture plant and livestock species on moorwissen.de • https://dss-torbos.de

Box 2.2 Overview of measures for establishment and maintenance of peat moss paludicultures

Peat moss paludiculture	(*Sphagnum spp.*) (see also implementation example in Chapter 7.2)
Site preparation	• Removal of the degraded, fertilised topsoil and creation of an even, largely vegetation-free peat surface • Creation of driveways (for maintenance mowing and harvesting carried out from the driveway; in future mainly for biomass removal) • Backfill embankments/dikes/driveways if necessary to maintain a water level
Water management	• Establishment of hydrological units with homogeneous water levels (cascades with large differences in relief to minimise topsoil erosion!) • Installation of automatic pumps including sensors in the irrigation ditches around the peat moss areas • Creation of irrigation ditches and culverts (exact and gradual raising with growing peat moss lawn necessary) • Adjustable overflows to raise the water level as the peat moss grows
Crop establishment, sowing	• Spreading moss cuttings (living peat mosses) with approx. 80 % initial cover, if possible at the beginning of the vegetation period, to form a closed peat moss lawn (Gaudig et al. 2018) • General figure: 80 m³ per ha
Area maintenance	• Mowing to suppress vascular plants, in future possibly by autonomous light equipment carriers • Clearing the irrigation ditches, pump maintenance • Mulching the driveways
Harvest	• Harvesting schedule: every 3 - 5 years (establishment period: 1.5 – 3 years) • Crawler excavator with mowing bucket, harvesting from the driveway • In the future: autonomous light equipment carriers or special track-based technology with bunke
Yield	• ~ 2 – 8 tonnes DM per ha*a
For more information	• www.moorwissen.de/torfmooskultivierung.html • Gaudig et al. (2018): *Sphagnum* farming from species selection to the production of growing media: a review. • Gaudig et al. (2017): *Sphagnum* farming on cut-over bog in NW Germany: Long-term studies on Sphagnum growth.

Black alder

You can find an overview of the cultivation, harvesting and utilisation of alder as a forestry use of wet fens both here and repeatedly in Chapters 2.3, 2.4 as well as Chapter 3. However, the guide essentially focuses on agricultural use. For more detailed information on alder as a paludiculture, see the literature references in Box 2.3.

Box 2.3 Overview of measures for establishment and maintenance of black alder stands on peatland

Black alder (*Alnus glutinosa*)	
Site preparation	• Creation of a free receiving water body or water levels that are close to ground level • If applicable, creation of borders to avoid overwatering of young plants • For grassland or arable fallow land: Mowing
Water management	• Free receiving water body; rapid groundwater flow required for highest quality • Avoid prolonged high overflow (will not be tolerated by plants)
Crop establishment, planting	• Biennial plant assortments • Planting density: 3,000 - 3,500 per ha with row spacing of 2 x 2 m • Planting on borders in wet locations • Planting with a spade or motorised manual method (one-man earth auger, planting hole drill), planting machines (with integrated tiller, if required) for larger areas • Use of suitable plant origins • Observance of the Forest Reproductive Material Act
Area maintenance	• Young growth management: after 8 years, removal of poorly shaped trees if necessary, targeted support of selected trunks by removing neighbouring trees • 4-6 thinnings required until harvest
Harvest	• Soil-conserving methods for thinning due to limited accessibility (e.g. cable pulling method) • Maturity after 60 - 80 years (for valuable timber)
Yield	• 600 – 800 m³ per ha of valuable timber, total growth up to 60 years of age
For more information	• ALNUS Guide (2005): Erlenaufforstung auf wiedervernässten Niedermooren. (Alder afforestation on rewetted fens). ALNUS-Leitfaden • Röhe & Schröder (2010): Grundlagen und Empfehlungen für eine nachhaltige Bewirtschaftung der Roterle in Mecklenburg-Vorpommern (Fundamentals and recommendations for sustainable cultivation of red alder in Mecklenburg-West Pomerania) • Sündermann & Röhe (2014): Vollmechanisierte Holzernteverfahren auf Nassstandorten (Fully mechanised timber harvesting processes on wetlands) • Sündermann et al. (2013): Bodenschonende Holzernte in geschädigten Eschenbeständen auf Nassstandorten. Erkenntnisse und Empfehlungen aus Fallstudien in Mecklenburg-Vorpommern. (Soil-conserving timber harvesting in damaged ash stands on wet lands. Insights and recommendations from case studies in Mecklenburg-West Pomerania).

2.2.5 Paludiculture of wet meadows and wet pastures (wet grassland; spontaneous stand development/succession)

In contrast to crop paludicultures, the conversion to wet grassland or wet meadow/wet pasture occurs through succession, i.e. a natural change in vegetation after high water levels are implemented. The plant population changes over the course of a few years from the time of rewetting onwards. By gradually raising the water level and avoiding high levels of waterlogging, the natural establishment and spread of water-tolerant species such as sedges and reed canary grass can be supported and large-scale rotting of the sward can be avoided. The biomass can still be harvested during this conversion and can also be fed into existing utilisation pathways at the start. The effort required for establishment is therefore significantly lower compared to crop paludicultures (see Chapter 2.2.4). Seeds from the original peatland vegetation can survive in the soil for many years. Wet meadow species can also be established at the edges of ditches and recolonise the area from there. Many plant species that are adapted to high water levels have buoyant seeds that can enter the area as a result of flooding events and ditch damming (Birr et al. 2021). In the absence of diaspores, it may be necessary to transfer mown material from existing wet meadows of regional stock, especially in the case of previously intensively utilised seed grassland.

Maintenance and management of wet grassland can be based on experience in landscape management (see Chapter 2.3). Conversion to wet grassland often results in synergies with existing nature conservation objectives, which means that it can also be implemented on areas with existing protected status (LM M-V 2017a, Tanneberger et al. 2020, Nerger & Zeitz 2021). This results in potential for large areas of wet meadows and wet pastures. On-farm conversion to wet meadow or wet pasture paludiculture is less costly (see Chapter 2.3) and involves fewer uncertainties compared to conversion to crop paludiculture. In the short to medium term, there is therefore great potential in switching to wet meadow and wet pasture management. Currently, there is already an estimated total area of around 15,000 hectares of wet meadows in Germany on which landscape management takes place and new utilisation methods are being sought for the growth. As the area of land increases and the associated availability of raw materials rises, a surge in innovation and demand for the use of wet meadow biomass can be expected.

Extensive grazing of wet and rewetted peatland is primarily established as landscape management. Small-framed grazing breeds and water buffalo, which also eat rushes, cattails and reeds, can be considered for (year-round) grazing on wet sites (Müller & Sweers 2016).

Birr et al. (2021) provide detailed information on grazing with water buffalo, as well as holdings containing red deer and horses as an animal-based utilisation option for wet fens along with grazing with robust cattle and geese on wet sites. The marketing options for animal-based methods as well as land and herd management are discussed in more detail in Chapter 3.1. Chapter 7.3 also presents a concrete practical example of grazing on wet meadows in Bavaria.

8 e.g. for protection of meadow-breeding birds, see e.g. https://life-limicodra.de/eng/

Box 2.4 Overview of measures for establishment and maintenance of wet meadows/sedge meadows

Wet meadows/sedge meadows	
Site preparation	• Reduced effort for soil cultivation, installation of cascades if required
Water management	• Free inflow, free receiving water body (but then water levels may drop in summer) • retention/waterlogging/overflow, 2-way-water regulation, if applicable • Overflow of winter water for water storage and/or creation of water reservoirs • Also watering in summer with short-term overflow for peat-preserving water levels
Crop establishment	• Spontaneous crop development • If applicable, transfer of cuttings
Area maintenance	• sward maintenance; to establish/maintain a viable sward, re-mowing may be necessary for grazing or additional maintenance cuts for mowing; sward maintenance only possible if compatible with any nature conservation/management requirements • Technology with low soil pressure (preferably 100 to 120 g/cm²) to avoid damage to the sward and peat body
Harvest	• Adapted conventional grassland technology or special track-based technology, • Harvesting of chaff or bales
Yield	• Annual harvest • Large sedge meadow: 2 - 12 tonnes DM per ha*a • Mixed stocks: 3 - 6 tonnes DM per ha*a
Source and further information	• Birr et al. (2021): Zukunftsfähige Land- und Forstwirtschaft auf Niedermooren. (Sustainable agriculture and forestry on fens.) Steckbriefe für klimaschonende, biodiversitätsfördernde Bewirtschaftungsverfahren (Profiles for climate-friendly, biodiversity-promoting cultivation methods) • Wenzel et al. (2022): Bioenergie aus Mooren. Thermische Verwertung von halmgutartiger Biomasse aus Paludikultur. (Thermal utilisation of stalk-type biomass from paludiculture).

Box 2.5 Overview of measures for establishment and maintenance of wet pastures

Wet pastures with water buffaloes (see also Chapter 7.3: Grazing in the Swabian Donaumoos)	
Site preparation	• Fencing with at least double electric fencing that is adapted to wet locations • Set up water supply (drinking trough) • Pasture shelter for protection from the cold and sun • Ensure access to a dry (mineral) part of the area as a retreat, with artificial creation of a paved resting area if required
Crop establishment	• Spontaneous succession
Water management	• Free inflow • Retention/waterlogging, short-term overflow in the summer after rotation.
Area maintenance	• Mowing out the fence line • If applicable, Re-mowing to maintain the sward
Stock density	• Stand pasture • In order to establish/maintain a robust, tread-resistant sward, it is necessary for grazing livestock to absorb as much of the growth as possible. This can be achieved by parcelling out and rotational grazing with a high stocking rate or by a long grazing period. The stocking rate (LU days/ha) is a suitable measure. Key figures for different vegetation types and pasture breeds are to be developed.
Growth	• Up to 840 g per day and calf
For more information	• Chapter 3.1 Animal-based procedures • Birr et al. (2021): Zukunftsfähige Land- und Forstwirtschaft auf Niedermooren. (Sustainable agriculture and forestry on fens.) Steckbriefe für klimaschonende, biodiversitätsfördernde Bewirtschaftungsverfahren (Profiles for climate-friendly, biodiversity-promoting cultivation methods)

2.3 Harvest Technology for paludiculture

To begin with, it should be noted that harvesting technology for paludiculture is still very much in its infancy. However, examples from landscape conservation or reed cutting show that effective management of wet sites is possible. In some cases, substantial modifications of available carriers are used, which have a large ground contact area to solve the problem of high tare weights. Many of these technological concepts are prototypes or have been developed for specific applications for use in relatively small areas. The existence of these prototypes only provides little information as to whether they have proved successful or whether they can be transferred to paludiculture on a large scale. For example, machines that can complete all work steps are preferred for small areas. However, large areas are to be harvested in the future, and paludiculture is also subject to economic efficiency pressure. Implementation of effective harvesting concepts therefore requires the separation of harvesting and transport vehicles. The tare weight and motorisation can be adapted to the respective activity alongside the requirements of a strong logistics chain. There has been a rapid development in specialised machines or the adaptation of existing technology in recent years. This makes it possible to realise a technical concept that is adapted to the necessary requirements. The following information should be taken into account when making a choice.

Technical requirements

The cultivation of paludicultures requires the use of technology for various activities:

- Site preparation
- Crop establishment (sowing or planting)
- Crop care (weed management, cupping cuts, reseeding if necessary)
- Harvesting including initial processing (cutting, chopping, baling, bundling, cleaning of e.g. reeds on-site if necessary)
- Transport of the harvested crop to the edge of the field or transfer point

Site preparation includes structural measures for water retention and irrigation, along with levelling of the area if required (see Chapters 7.1 and 7.2). If initial establishment of stalk-type crop paludicultures takes place before the water levels are raised, no adapted special technology is required (see Chapters 2.2.1 and 7.1). The establishment of peat moss paludiculture or measures in which the sward is removed over a large area (levelling) already requires technology with low ground pressure when preparing the area and for "sowing", such as a converted snow groomer fitted with a semi-mounted manure spreader for spreading the peat moss (see Chapter 7.2).

Depending on the condition of the sward, the use of adapted agricultural technology or specialised technology is necessary for crop care, harvesting and removal of the harvested crop from the field, and is described below for the various types of paludiculture. Overloading, transport and storage can also be carried out using existing agricultural machinery.

Location fundamentals

The use of (harvesting) technology on wet and waterlogged peatland depends on the load-bearing capacity of the sward and the stability of the subsoil. Vegetation, water level and soil condition or the degree of degradation are further influences. The load-bearing capacity is essentially characterised by the species composition and sward maintenance. The two parameters of shear strength and penetration resistance (Box 2.6) can be used to assess the trafficability and to estimate the effects of traffic on the peatland soil (Wiedow et al. 2016).

Additional information:

- Chapter 4 “Harvesting and logistics" in Wichtmann et al. (Ed.) (2016): Paludiculture – cultivation of wet peatlands
- Chapter 2.3 “Ökonomie/Ökobilanz mal durchgerechnet: (Economy/life cycle assessment - a thorough calculation;) So lohnt es sich für Betrieb und Klima“ (So it pays off for the company and the climate") in Wenzel et al. (2022): Bioenergie aus nassen Mooren -Thermische Verwertung von halmgutartiger Biomasse aus Paludikultur (Bioenergy from wet peatlands - thermal utilisation of stalk-type biomass derived from paludiculture). p. 38-48.
- Scientific monitoring of grant recipients of the ERDF funding programme for peatland protection (ProMoor), Eberswalde University for Sustainable Development,
- Other stakeholders in various federal states, e.g. landscape conservation associations in peatland-rich regions, Lokale Aktion groups and Stiftung Naturschutz (Schleswig-Holstein), ARGE Klimamoor (Brandenburg), ARGE Donaumoos (Bavaria), 3N Kompetenzstelle Paludikultur (Lower Saxony) have practical experience and make this available i.e. at field days.

Box 2.6 Shear strength & penetration resistance

The shear force is a force whose direction of action is parallel to a surface. Shear strength indicates the maximum shear stress with which a body can be loaded before shearing (Kraschinski et al. 1999, Schmidt 1980, Schreiner 1967). The shear strength is measured with what is known as a shear vane (Prochnow & Kraschinski 2001).

Penetration resistance is the resistance of the ground to a load. It depends on the storage density, water content, pore size distribution and structure of the organic matter (Horn 1984). Penetration resistance is measured with the penetrometer (Dürr et al. 1995).

The shear strength provides information about the load-bearing capacity of the sward, the penetration resistance provides information about the strength of the subsoil (MLUK 2023, Wiedow et al. 2016). The combination of penetration resistance and shear strength determines how deep the harvesting technology sinks into the peat body depending on the respective soil pressure. The deeper the contact surface (wheel, chain) penetrates, the steeper the "hill" that the technology has to "drive up" and the higher the tensile forces acting on the sward. If the acting tensile forces exceed the shear strength, the sward will tear and be broken through.

2.3.1 The challenges of managing wet and waterlogged peatland soils

Root penetration in the top 10 cm plays a key role in trafficability (Schmidt 1995). Below the rooted layer (15 - 30 cm depth), the shear strength of dry, degraded peat with an aggregate structure is higher than that of gyttjas (MLUK 2023). It increases with the density of the plant population and decreases with higher soil moisture. An earthified, i.e. heavily degraded peatland soil in turn has a single-grain structure with only low cohesion and thus exhibits only low shear strength (Wiedow et al. 2016) and is not very stable after rewetting. The load-bearing capacity of the sward is lowest in floating grass plant communities („Flutrasen"), increases in reed canary grass and reed beds and is highest in sedge meadows (Prochnow & Kraschinski 2001, Wiedow et al. 2016). After destruction of the sward, it tends to be mainly species of floating grass that colonise an area, which significantly reduces the carrying capacity even in older sward damage and other disturbed areas (MLUK 2023).

When rewetting grassland - especially during a gradual conversion of vegetation until reed canary grass stands and sedge stands have formed a dense root system - **sward maintenance** and the avoidance of sward damage during cultivation of the area are essential components in the management of (stalk-type) paludicultures or wet grassland.

Another challenge for productive stands is the high volume of biomass during harvest. The requirements for mowers, pick-up and feed devices as well as the high (soil-conserving) transport effort to the edge of the field are correspondingly high. The low bulk density or large volume poses a challenge in the case of dry-loaded crops and requires processing in the field (chopping, bundling, pressing); in the case of fresh biomass, high weight poses a problem and minimises the payload (Dahms et al. 2017). There is still a need for further development for the efficient transport of fresh, i.e. heavy biomass to the edge of the field or transfer point. Fresh cuttings must either be dried externally (actively or passively) or ensiled, possibly with the addition of ensiling aids to ensure that the end result can be stored.

Adaptation of site management

An adapted type of cultivation and logistics should also be taken into account alongside the use of adapted harvesting technology (see below). These include the following points (based on MLUK2023, Schröder & Dettmann 2016, Wichmann et al. 2016, Wiedow et al. 2016, Schröder et al. 2015):

- Construction of driveways via which the harvest area can be reached (ditches in the centre of the area, not along the path!)
- If applicable, filling of ditches to provide flat access from existing paths,
- Installation of additional access routes,
- Calculation of transportation resulting from the infrastructure, biomass volume and loading capacity,
- Consolidation of the apron on crossings or access roads by filling with mineral soil,
- Creation of paved storage and handling areas on the edge of the field,
- Lane planning to avoid tight curve radii and multiple crossings,
- Marking of trouble spots or GPS-supported mowing with the aid of a side mower,
- Knowledge of the area and driver experience are basic requirements.

Technical adjustments to the machines used

Minimising ground pressure is the primary aim of such adapted technology. A guideline value of approx. 100 g/cm² is often recommended in order to avoid damaging the sward and the peat body

(Wichmann et al. 2016). In addition to adapted cultivation, there are several ways to reduce the ground pressure of the machinery used:

- Reduction of overall weight by using precision technology or lightweight components
- Enlargement of the contact area
    - With conventional agricultural machinery:
        - Double/twin tyres, with rounded shoulder and large lug contact area
        - Lowering the tyre pressure
    - Delta drives
    - Track-based special technology
    - Wheel-based special technology

It is also important to balance the weight of the machine, harvesting attachments and the payload. If harvesting and transport vehicles are used separately, the working width of powerful harvesting machines can be increased, increasing the impact force whilst reducing the proportion of the area that is driven over. Light transport vehicles can then be used to recover the biomass.

There are various **advantages and disadvantages of technology adaptations**, which are summarised below (extended according to Wichmann et al. 2016, Schröder et al. 2015, MLUK 2023, Wenzel et al. 2022):

Small-size technology (hand-guided technology, single-axle tractors, small tractors) can only be used on small areas due to their small working width and therefore low area output. For example, a detailed overview can be found in Wichmann et al. (2016). There is potential in the future use of autonomous light (swarm) technology, e.g. equipment carriers for individual process steps (maintenance cuts on peat moss areas, transport of biomass to the edge of the area and others).

Adapted grassland technology has a high area output during mowing, but is dependent on the weather ("hay weather", Wenzel et al. 2022; Fig. 2.9) and also depends on sward maintenance. It can be used in dry weather with water levels dropping in summer. The biomass is transported in bales to the edge of the field. Sometimes individual bales may be transported due to its weight. This should be avoided as far as possible by adapting the harvesting technology and optimising the logistics concept. The use of **twin tyres** leads to longer set-up times, as a second set of tyres must be fitted/removed at the edge of the field with the help of a second tractor. A **lowerable tyre pressure** increases the contact area and thus reduces the contact surface pressure. Tyre pressure control systems make it easy to regulate the tyre pressure, thus reducing diesel consumption, working time and wear on tyres. Powerful tractors can be equipped with **Delta drives** (Fig. 2.9 on right). These can achieve a high impact force with large working widths, albeit at a high weight. In order to minimise the load on the ground, do not stop in the area and select a consistent working speed. Nevertheless, the customisation options for conventional agricultural technology are not sufficient to reduce the soil pressure to approx. 100 g/cm², which is the level necessary for cultivation of wet and waterlogged peat soils with peat-preserving water levels even in summer.

Wheel-based special technology in the form of balloon tyres with low pressure is often used in reed cutting and achieves the low level of ground pressure that is required. This is associated with a high level of labour input (Fig. 2.6, 2.7). They often use old machines with limited engine power or their own designs/replicas. In the case of higher overflow, there is a risk of floating and thus manoeuvring difficulties, as well as possible ground damage due to slippage.

Track-based special technology protects the soil whilst having the required impact force to use harvesting periods efficiently and reduce costs (Fig. 2.6, 2.8). Use of track vehicles can cause damage to the sward when travelling around (tight) bends and repeatedly passing over the same areas (Närmann 2018, Schröder et al. 2015). This can be reduced by adapting the chains (e.g. rubber chains, Wichmann et al. 2016). The chains should have a width-to-length ratio of 1:4 to 1:5, as long chains increase the shear forces when cornering (Schröder et al. 2015). Wider tracks increase the contact area, reducing the ground pressure. However, as track technology has to be transported by low loader, the machine width should not exceed 3 metres to allow transport on roads. Alternatively, the chains must be removed at great expense or a special permit must be requested due to excess width. Increasing the transport capacity to the edge of the field can be achieved by increasing the loading capacity and/or compacting the biomass during the harvesting process. A disadvantage with a larger payload is the changing weight distribution of the machine and the increase in total weight. A coordinated harvesting and logistics concept is essential for high output and area performance. Chain-based special technology is also linked to high investment and maintenance costs, which must be compensated for by a high level of use (Wenzel et al. 2022).

The various special technology options for selected paludicultures are presented below.

2.3.2 Harvest of stalk-type paludiculture

A detailed overview of harvesting technology, harvesting methods and technical requirements is provided by Schröder et al. 2015, as well as Wichmann et al. 2016, Schröder et al. 2016 and also Dahms et al. 2017. Usage and testing of adapted technology for soil-conserving management of peatland sites as part of the ERDF funding guideline for peatland protection in Brandenburg (2020–2023)[9] was supported in practice to determine the effects on peatland soil and to make this experience available for further applications. Interim results of this scientific monitoring are presented in MLUK (2023). So far, landscape management has been the main driver for (further) developments of adapted or specialised technology for wet peatland soils (e.g. Wijns et al. 2018), the technical challenges of harvesting (crop) paludicultures are also increasingly being addressed (e.g. Korthorst 2022, Dahms 2017, GesaSpan[10] research and development project and TyphaSubstrat[11]).

A model calculation of working hours for harvesting paludicultures clearly shows that use of track- and wheel-based special technology is more time-consuming than use of adapted agricultural technology. However, the latter cannot be used on wet peatland soils because the ground pressure is too high (see above, Wenzel et al. 2022). Modern roof reed harvesting technology can already achieve extremely high harvesting performance thanks to efficient transport of reed bundles in large bundles as well as the transfer of these to transport vehicles. The transfer to transport vehicles significantly reduces journeys made by harvesting machines. Maintenance and upkeep of machinery takes more time compared to adapted agricultural technology which is carried out to minimise machine downtime due to malfunctions and defects, which occur, among other things, due to the increased load on the machines when used on wet soils (Wenzel et al. 2022).

Harvesting of the biomass already determines the downstream logistics chain, such as the type

9 https://www.hnee.de/forschung/projekt/moorschutz-promoor
10 https://pflanzen.fnr.de/projekte/projektuebersicht/projekte-details?fkz=2220MT002X&cHash=8b95b8c02314a2f1a5815d276fdfa319
11 https://pflanzen.fnr.de/index.php?id=11381&fkz=2220MT003B

of transport, the storage options as well as processing and utilisation options for biomass. Specific requirements for the harvested crop in terms of ingredients and/or forms of processing must be taken into account during harvesting depending on subsequent use. For example, this can relate to the provision of certain fibre and stalk lengths, the separation or cutting off of individual plant parts during harvesting, the type of compression and (residual) moisture required for storage and further distribution (see Chapter 3). The desired or undesired ingredients for further utilisation - such as protein content, cellulose and hemicellulose content, lignin content, but also element content - are determined by the harvest date, among other things. This in turn has an impact on the technology that can be used.

Reed

Harvesting of roof reed (reed cutting) is traditionally established on small areas, especially in northern Germany (Fig. 2.6). Seiga machines from a Danish manufacturer with balloon tyres were primarily used for this purpose, although these are no longer in production. Replicas of this machine are used for reed harvesting in Poland and Ukraine. Recently, new or converted track vehicles have been increasingly used. There are several decades of experience in the Netherlands with the use and continued development of track-based harvesting technology (Wichmann et al. 2016). Reeds can also be harvested during summer mowing in the form of chaff or bales (Tab. 2.3). However, it should be borne in mind that summer mowing gradually pushes back the reeds and results in a shift in plant species composition, e.g. towards sedge reeds.

Cattail

Trafficability using specialised wheel- and track-based technology were successfully tested on various cattail stands during summer and winter in Germany and the Netherlands (Korthorst 2022, Neubert 2022, Dahms 2017; Fig. 2.7). However, growing interest in cattail as a raw material for material utilisation and the foreseeable increase in cattail cultivation areas make it clear that there is a great need for development in efficient mechanical planting, adapted mower heads and optimised harvesting methods. Questions about downstream logistics, especially drying, storage and processing of the harvested crop, also need to be answered. These questions are being addressed, amongst others, in the Paludi-PRIMA (2019 - 2022)[12], TyphaSubstrat (2021 - 2024)[13] and Paludi-PROGRESS (2022 - 2025) research and development projects.

An important aspect is the regional availability of specialised harvesting technology in order to be able to react flexibly to weather conditions without having to stick to long-term fixed harvesting dates (Neubert 2022, Theuerkorn 2001). Harvesting chaff that is sucked/blown into a bunker is also feasible (e.g. Wichmann 2022; see Chapter 7.1). This requires optimisation of the process, including adjustment of the machine parameters (output, size, etc.) to the biomass, the technical challenges for the mower with a high (and possibly moist) biomass volume as well as the bunker capacity.

Leaves/stalks and cobs can be used in different ways. It may therefore be necessary to harvest the different parts of the plants separately or to separate them during harvesting. For example, there is a need for development in the harvesting of leaves in a parallel position and stems with or without cobs, as is desirable for processing into making some building materials (Theuerkorn 2001). There is initial experience in the Netherlands that an early first cut of the cattail allows "cob-free" pure leaf mass to be harvested without the pithy stem in the second cut (pers. comm. C. Fritz 2021). Further investigations are still pending. Previous

12 https://www.moorwissen.de/de/paludikultur/projekte/prima/index.php
13 https://www.moorwissen.de/typhasubstrat.html

Tab. 2.1: Reed harvesting for use for thatching (extended according to Wichmann et al. 2016)

Period	Winter (January - March)
Technology used	Wheel-based or track-based special technology
Mower/ process	Cutter bar, feeding of the dry, whole and upright stalks to a binder via a spindle or chain, binding of raw bundles, transport (possibly by conveyor belt) to the loading area, in some cases acceptance and stacking of the bundles by hand
Harvest product	(dry) bundles; mowing, binding and transport in a single-stage process, reloading the bundles onto an escort vehicle for removal if required

Fig. 2.6: Reed cutting with Seiga and track vehicle technology from Hanze Wetlands on the island of Rügen. Examples of single-stage harvesting methods. Photos: T. Dahms

harvesting tests with harvesting technology from reed cutting (e.g. as part of the German Peatland Protection Dialogue[14], 2015 - 2018 and TyphaSubstrate projects) were not yet satisfactory. There is a need for development regarding customised cutting units, feeding of the biomass to the binder and binder devices, removal of external biomass (cleaning) and suitable conveyor systems from the cutting unit to the bunker. Harvesting tests have shown that technology from the roof reed harvest can only be used to a limited extent, as cattail bundles tend to be conical or pear-shaped compared to parallel reed stems (with a much higher volume near the ground) and the conveying and binding devices from the roof reed harvest are often blocked as a result.

Another challenge in mechanised harvesting is the separation of the fruit stalks (cobs) and the leaf and stem mass. It may be possible to transfer experience from harvesting hemp, where leaves and stalks are harvested and separated at the same time[15]. Otherwise, the separation of leaf and stem mass as well as the fruit stalks must be carried out after harvesting, during further processing or pre-processing. There is also a need to optimise drying of the harvested material, as cattail biomass harvested in winter in northern Germany also has a water content of approx. 70 % (Geurts et al. 2020, Neubert et al. 2022). For chopped harvested material, tests were carried out in a wood chip drying system with solar thermal support and a trailer drying system with waste heat from a biogas plant (Neubert et al. 2022). It has been shown that the biomass must be circulated regularly in any case, e.g. by means of an automatic agitator. It was possible in Bavaria to harvest cattails in winter and store them in bundles under cover without active post-drying (Theuerkorn 2001). Experience in the Netherlands confirms the option of passive drying of smaller quantities, both in the open air

14 https://greifswaldmoor.de/das-projekt.html

or beneath a roof (pers. comm. C. Fritz, 2022), or underneath a fleece.

Wet meadows (sedges, reed canary grass and other wet meadow grasses)

Raising water levels and converting drained peatlands into wet meadows is less complicated compared to cultivated crops and could potentially cover an enormous area. Focus should be on low contact surface pressure, high area output and optimisation of the logistics chain within continued development of harvesting technology for wet meadows. There is experience of harvesting wet meadows from landscape management, but this is only designed for maintenance of small areas. There is a need for development in adapting the logistics chains of wet meadow utilisation to the changed site characteristics. Separation of harvesting and transport vehicles is necessary to achieve the required impact force. Balloon tyres have proven their worth in reed harvesting and have great potential for biomass transport in particular. As no manufacturer is yet available on the market, snow groomers were used as an alternative and conversion of these is well established at this point. However, converted snow groomers are overpowered and less suitable for transport-

15 https://www.agrarheute.com/technik/hanfernte-john-deere-t660i-559048

Tab. 2.2: Cattail harvest

Period	Summer and winter (November/December)
Technology used	track-based special technology
Mower/process	Cutter bar mower (with adapted knife speed), possibly a corn header, feed to binder, binding or load and transport in another manner in parallel position if possible. (There is a need for further development!) Flail mulcher and forage harvester in front attachment, chute feed into a semi-mounted bunker. Transport by harvesting vehicle from the field to the transfer point. Tipping directly onto a trailer for removal if possible, alternatively load the tipped crop by crane
Harvest product	Bundles or loose chaff (single-stage process)

Fig. 2.7: Harvest trial on a cattail stand near Anklam. Successful harvest with a Seiga in 2018. Photo: T. Dahms

ing biomass due to their own tare weight. track-based new technology from various manufacturers is already available, but does not yet solve the problem of the high tare weight (see MLUK 2023, Dahms 2017, Wichmann et al. 2016). Use of standard agricultural attachments is possible thanks to front and rear three-point linkages and PTO connections. For multi-stage processes (Fig. 2.9), all machinery used must be adapted to the soil conditions, e.g. by additionally equipping light balers with a double axle and twin tyres or using track-based combinations (MLUK 2023; Dahms 2017). In the future, it is to be expected that advanced autonomous equipment carriers will also be widely used in wet meadow management.

If it is not possible to dry the cut in the field due to high water levels, fresh, i.e. heavy biomass must be transported to the edge of the field or transfer point in a way that is gentle on the soil, then dried or preserved away from the field. In the case of downstream drying, this must be carried out using primary energy as efficiently as possible.

2.3.3 Harvesting peat moss paludiculture

The world's first mechanical harvest of a peat moss paludiculture was carried out in 2016 using a mowing bucket, which harvested the 10-metre-wide peat moss production areas from a driveway using a long arm excavator. The mosses are loaded from the excavator into a tractor-drawn loading trailer (dumper), which also stands ready on the driveway and transports away the biomass.[16] The crop can be dried on a windrow at the edge of the field or on a paved surface to a water content of 70 - 80 % (Wichmann et al. 2020) before further processing. The driveways are formed from earthified peat and cover a large area. They continue to be a significant source of GHGs. The ratio of driveway to cultivated area must be optimised in the future. Concepts for managing peat moss areas with fewer driveways are currently in development.

A successful harvesting trial with a special track-based technique took place on a section of the peat moss paludiculture area in Hankhauser Moor/ Lower Saxony in December 2021. The track vehicle had a max. contact surface pressure of 115 g/cm², driving directly on the peat moss lawn before harvesting the peat moss in a single pass with a front-

Tab. 2.3: Harvesting wet meadow biomass in summer, autumn or winter as chaff and bales.

<table>
<tr><th>Technology used</th><th>Customised agricultural machinery</th><th>track-based special technology</th></tr>
<tr><td>Period</td><td>Summer</td><td>Summer, autumn, winter</td></tr>
<tr><td rowspan="3">Mower/process</td><td>Single stage: Harvesting with forage harvester and direct transfer to a transport trailer moving parallel to it</td><td>Single stage: Forage harvester and mulcher or combine harvester cutting unit and direct pick-up of the chopped crop through a chute into a semi-mounted or trailed bunker or feed into a semi-mounted baler (Fig. 2.8)</td></tr>
<tr><td colspan="2">Two-stage: (1) Mowing and swathing (swathing with an extra vehicle directly after cutting if necessary), (2) Collecting the fresh mass with a forage harvester or harvesting trolley and transporting it to the edge of the field (where it is further processed into wrapped bales/storage silos)</td></tr>
<tr><td colspan="2">Three-stage: (1) Mowing with cutter bar or rotary mower, (2) Swathing, turning and baling of hay bales, (3) Removal of hay bales to the edge of the field (Fig. 2.9 and Fig. 2.10)</td></tr>
<tr><td>Harvest product</td><td colspan="2">Dry: Hay bales or loose chaff
Fresh: Silage bales or loose chaff (silo)</td></tr>
</table>

Fig. 2.8: Single-stage harvesting method: Harvesting technology for chaff, winter harvesting. Harvesting technology: Softrak 120 (Loglogic) with ELHO double forage harvester and 11 m³ bunker. Only suitable for special crops or in landscape management. Photo: T. Dahms, 2021.

Fig. 2.9: Examples of multi-stage harvesting methods. Left: Summer mowing with track vehicle technology; centre and right: with technology adapted for grassland. Photos: T. Dahms; right: S. Fischer.

Fig. 2.10: Track vehicle with baler. Photo: T. Dahms.

mounted chopper, which was transported upwards by an auger. Some of the water has already been pressed out. The peat mosses were then transported through a chute into a semi-mounted bunker with a loading capacity of 11 m³ (pers. comm. G. Gaudig, 2022).

Initial practical tests have been taking place on other areas at the same trial site since spring in 2022, with an autonomous, remote-controlled equipment carrier that is used to mow and harvest the peat moss. The vascular plants are mulched during maintenance. Practical trials for harvesting peat moss are currently underway. (as of June 2022)[17].

Tab. 2.4: Harvesting peat moss

Period	All year round
Technology used	Proven: Excavator on driveway and escort vehicle for removal Tested: track-based special technology In development: autonomous equipment carriers
Mower/ process	Mowing bucket, which mows off the upper 5 - 10 cm of the peat moss and collects, or track vehicle with chopper in front attachment, feed with auger and chute in semi-mounted bunker Fig. 2.11
Harvest product	Loose peat moss (chopped or cut whole mosses)

Fig. 2.11: Harvesting peat moss biomass. Left: Mechanical peat moss harvesting with mowing bucket. Right: Test harvesting with chain-based technology (Loglogic). For more information, see Chapter 7.2. Photos: left: P. Schroeder, right: G. Gaudig.

16 https://www.moorwissen.de/doc/paludikultur/imdetail/infotafeln_torfmooskultivierung/Infotafel%20Technik.pdf

17 https://www.iasp-berlin.de/abstract/kooperationsprojekt-entwicklung-eines-terrestrischen-sphagnum-erntefahrzeugs, the development is funded via BMWK (see Chapter 6)

2.3.4 Harvesting the alder

Selection of a suitable harvesting method for alder timber on wet sites depends on various site and crop parameters, including groundwater balance, crop size and shape, maximum cutting distances, total cutting volume, average unit mass of the harvested trees and the cutting rate per cutting route (Röhe & Schröder 2010). The cable crane method is the most soil-friendly method (Fig. 2.12). The logs are cut by hand using a motor, which are then roped by a remote-controlled trolley and moved to or along the cable crane route using the back-grinding method (Röhe & Schröder 2010, Sündermann et al. 2013).

Fig. 2.12: Cable crane technology for recovering manually felled logs. Photo: P. Röhe

2.4 Costs

A detailed overview of the rewetting costs as well as the establishment and management of paludiculture areas can be found in the background paper "Lösungsansätze zum Erreichen der Klimaschutzziele und Kosten für die Umstellung auf Paludikultur" (Solutions for achieving climate protection targets and costs for converting to paludiculture) by Wichmann et al. (2022a)[18] . A summary is provided in this guide. Contrary to the usual presentation, the costs are not directly compared with revenues here, as hardly any data on revenues is available to date or these are currently highly dependent on individual marketing approaches and are only transferable to a limited extent. Chapter 3 therefore specifies and categorises revenue potentials for various uses and puts estimates on future markets.

Project executors and advisory organisations may be be asked directly for regional experience about implementation of peatland rewetting and the costs involved. In Bavaria, Lower Saxony and Schleswig-Holstein, the organisations with experience include landscape conservation associations, Lokale Aktion groups and peatland climate managers. However, this experience is based on implementation of nature conservation measures. To date, paludiculture has often been implemented in close collaboration with research and development stakeholders. The growth in knowledge, especially in federal states with a high concentration of peatlands, is very dynamic. Recommendations can also be taken from other instructions or guidelines (for an overview, see Chapter 2.1), for example from the "Leitfaden zur Renaturierung von Feuchtgebieten in Brandenburg (Guide to nature restoration of wetlands in Brandenburg)“ (LfU Brandenburg 2004).

18 https://www.dehst.de/SharedDocs/downloads/DE/projektmechanismen/Hintergrundpapier-loesungsansaetze-paludikultur.pdf?__blob=publicationFile&v=2

Further information

- Wichmann et al. (2022a): Lösungsansätze zum Erreichen der Klimaschutzziele und Kosten für die Umstellung auf Paludikultur. (Hintergrundpapier zur Studie „Anreize für Paludikultur zur Umsetzung der Klimaschutzziele 2030 und 2050“) (Background paper to the study “Incentives for paludiculture as part of implementation of 2030 and 2050 climate protection targets”)
- Birr et al. (2021): Zukunftsfähige Land- und Forstwirtschaft auf Niedermooren – Steckbriefe für klimaschonende, biodiversitätsfördernde Bewirtschaftungsverfahren (Sustainable agriculture and forestry on fen sites - profiles for environmentally friendly cultivation methods that encourage biodiversity).
- Pfister & Oppermann (2021): „Ökonomie“. In: Närmann et al. (Hrsg., 2021): Klimaschonende, biodiversitätsfördernde Bewirtschaftung von Niedermoorböden. BfN-Skript 616.
- LM M-V (2017): Umsetzung von Paludikultur auf landwirtschaftlich genutzten Flächen in Mecklenburg-Vorpommern. Fachstrategie zur Umsetzung der nutzungsbezogenen Vorschläge des Moorschutzkonzeptes (Implementation of paludiculture on agricultural areas in Mecklenburg-Western Pomerania).
- Chapter 6 “Economic Aspects of Paludiculture“ in Wichtmann et al. (Hrsg.) (2016): Paludiculture - cultivation of wet peatlands. p. 109 – 142
- Wichmann et al. (2022): Herleitung von Förderpauschalen zur Umsetzung von Moorklimaschutzprojekten. GMC-Schriftenreihe 01/2022.

2.4.1 Site creation, infrastructure and crop establishment

The cost of setting up a cultivated area and establishing a crop depends on local conditions and the needs of the crop in question, as well as the size of the area. If, for example, the area has a free receiving water body and no demarcation by embankments is required, installation and investment costs are considerably lower than in a case where the entire area has to be designed as an island in a drained environment for a higher water level (see the example in Chapter 7.1). Therefore, the costs below are shown with larger ranges in order to take the specific conditions of each case into account.

In principle, it is necessary to clarify which costs are only allocated to rewetting and which to the production process, and thus which costs are to be allocated to climate protection and which to the maintenance of management (see Chapter 6.1). The same applies to ongoing costs that may need to be included in an operational calculation. One of the main arguments for the implementation of paludiculture is to absorb the running costs required to maximise the climate protection performance of an area through a management concept. However, this is also possible on areas without harvesting and subsequent use of the biomass (climate protection area), e.g. by means of continued investment in the climate. They are itemised below for all phases, regardless of who bears the costs. In individual cases, especially if the costs are financed via different funding instruments, state aid regulations and funding conditions must be checked in order to avoid double funding in future applications for AECM, for example. However, the costs should also be broken down in future when marketing the ecological services provided.

Infrastructure for the establishment of paludiculture (site preparation)

In contrast to previous rewetting measures, measures to realise differentiated water management must be implemented on a larger scale, which may also include hydrological subdivision and an active water supply. In addition, measures are required to ensure accessibility and removal of the harvested material. This requires the construction of a considerable number of driveways, which can also be used for hydrological subdivision.

Establishment of reed and cattail paludiculture crops

Targeted establishment is recommended for a reliable harvest of specific species or targeted biomass qualities on peatland sites that are to be rewetted. In contrast to succession, establishment of a harvestable plant population is faster, resulting in denser and more homogeneous crops. It is possible to select desired qualities by using seed from selected stocks with desirable characteristics and by breeding new varieties. In addition, the specific site characteristics must be taken into account when selecting seeds and varieties. Pilot projects have provided experience with establishment of reeds and cattails: “Schilfprojekt“ (reed project) in Biesenbrow (Brandenburg, Wichtmann 1999), “Rohrkolbenanbau in Niedermooren“ (cattail cultivation on fens) (Bayern, Pfadenhauer & Wild 2001). Current projects are underway in Bavaria (MoorUse project[19]), Mecklenburg-Western Pomerania (Paludi-PRIMA[20]) and Lower Saxony (Produktketten aus Niedermoorbiomasse - product chains from fen biomass[21]), among others. However, previous pilot areas for crop paludicultures are a maximum of 10 ha in size and are designed as "wet islands" in a drained environment (Neubert et al. 2022).

Cultivation of reeds and cattails requires permanently high water levels. This generally requires more complex construction measures than conventional rewetting. They depend heavily on initial conditions (relief, condition of the sward, competitive vigour of initial vegetation, etc.). This also applies to possible site preparation (Tab. 2.5). Depending on the initial situation, different measures are required to prepare the seedbed or planting. Competition must be shifted in favour of the crop to be cultivated. When sowing, it may be necessary to at least partially open up the existing sward (slit sowing) or to cause it to rot by deliberately overflowing. Sowing into the existing sward has already been successfully tested (for cattail). Establishment by planting pre-grown seedlings is more favourable in terms of site preparation and less risky in terms of successful establishment. However, it is more cost-intensive than establishment by seed due to the required material in terms of young plants and their application.

The lower value of the total costs listed in Table 2.6 takes into account favourable initial conditions with simple water management and establishment by sowing, while the higher value includes high investment costs for infrastructure and water management as well as establishment via planting (for an explanation and sources, see Wichmann et al. 2022a).

19 https://www.hswt.de/forschung/projekt/958-mooruse
20 https://www.moorwissen.de/prima.html
21 https://www.3-n.info/projekte/laufende-projekte/produktketten-aus-niedermoorbiomasse/

Tab. 2.5: Overview of possible cost factors for establishment of paludicultures with reed and cattail

Phase	**Possible cost factors** (depending on the starting position)
Site preparation	
Site preparation	Levelling/sloping, terracing (depending on relief and slope) Removal of the sward Backfilling of dams/embankments Excavation of external ditches for drainage water (for "island solutions") Backfilling of trenches Searching for shafts and capping old drainage pipes
Water management	Hydraulic engineering measures (e.g. water abstraction, irrigation, adjustable overflows, construction of water storage basins) Infrastructure for free access Acquisition and operation of fixed/mobile pumps
Establishing of crops	
Seed	Seed preparation (e.g. pelleting) Preparation of the seedbed (mowing and clearing, creation of open soil by damming and rotting out the sward, partial cutting, slitting in the course of seed sowing) Spreading (sowing by drone, by water drift, drilling) If applicable, rolling
Planting	Cultivation/purchase of plants (quantity depends on plant density) Preparation of the planting bed (mowing with clearing if necessary, mulching of the sward) Planting (row spacing, plant spacing in the rows) Scaring off animals to protect the young plants

Tab. 2.6: Costs for the establishment of paludiculture crops with reed or cattail (Wichmann et al. 2022a)

Cost type	Unit	Costs in €
Construction measures & site preparation	EUR per ha	1.500 – 15.000
Establishing of crops		
1) Seed variant		
- Seeds (extraction, purchase)		No data
- Sowing	EUR per ha	0 – 200
2) Planting		
- Planting material (5.000 – 10.000 plants per ha)	EUR per plant	0,30 – 0,85
- Planting	EUR per ha	500 – 5.500
Investments in irrigation technology	EUR per ha	0 – 4.000
Total	**EUR per ha**	**2.000 – 30.000**

Crop paludiculture with peat moss

When establishing peat moss paludicultures on former bog grassland or after peat extraction, the purchase of seed material and the investment costs for water management are decisive cost factors (Wichmann et al. 2017). The cost data in Table 2.7 come from a pilot area in the Hankhauser Moor area near Oldenburg (see Chapter 7.2), where peat moss paludiculture has been trialled on 17 ha since 2011 under the leadership of the University of Greifswald and in close cooperation with the Moorkultur Ramsloh peat plant and other partners (MOOSGRÜN, MOOSWEIT and OptiMOOS projects). Costly steps in establishing this paludiculture include installation of water management facilities for water management and the production (or purchase) of peat moss seed material for the establishment of the crop.

Wet meadows and pastures (wet grassland)

Wet meadows develop from grassland stands through spontaneous succession, which means that targeted establishment incurs lower costs for establishment of the stand. However, depending on the location, the costs for establishing the area can be just as extensive as for planting reed and cattails. If seeding or planting, e.g. of sedges, is to be carried out to speed up establishment and conversion of the plant population, then the estimates for preparing the area as well as seeding and planting reed and cattail (see above) can be used as a guide. It may be necessary to kickoff with transferred mown material from areas with the target vegetation, especially in species-poor grassland. The use of organic seed should also be considered if the target species do not appear as a companion species in the existing sward or in the immediate vicinity.

Tab. 2.7: Establishment costs for a pilot area with crop-paludiculture for peat moss on former raised bog grassland, given as proportional costs per net production area (EUR per ha) (Wichmann et al. 2022a, according to Wichmann et al. 2020)

Cost type	Unit	Scenario A High costs	Scenario B Average costs		Outlook for reduced costs
		2011	2016	Compared to 2011	Estimates
Construction measures & site preparation	EUR per ha	14.615	36.287	+148%	14.000
Investments in water management	EUR per ha	45.952	22.334	-51%	10.000
Peat moss "seed material"	EUR per ha	58.467	34.779	-41%	20.000
Stock establishment "sowing"		8.856	5.046	-43%	5.000
Total	**EUR per ha**	**127.862**	**98.446**	**-23%**	**49.000**

Black alder

Wichmann et al. (2022a) represent the process costs of initial afforestation from land preparation to secured cultivation for the production of valuable trunk wood. In addition to land preparation (soil cultivation), costs are incurred for the purchase of young plants and for establishment of planting/cultivation. The plant assortments and plant density are factors which have a particularly strong impact on costs. The crop establishment costs for afforestation with black alder are shown at Table 2.8. This does not take into account any costs for site preparation such as raising (and maintaining) the water level. Typically, no water level regulation is required for black alder crops. Instead, before afforestation with black alder, it must be verified that the water levels are permanently stable and that prolonged overflow can be ruled out (Wichmann et al. 2022a).

Tab. 2.8: Crop establishment costs for black alder afforestation (Wichmann et al. 2022a)

Cost type	Unit costs in €	
Planning and construction costs	EUR per ha	0
Number of plants	Units per ha	3.000 – 3.500
Unit price per plant	EUR per plant	0,75 – 1,50
Planting	EUR per plant	0,20 – 0,50
Total	**EUR per ha**	**2.850 – 7.000**

2.4.2 Management and harvesting costs

Cattail and reed

Management costs are incurred for cattail and reed cultures primarily through water management and area maintenance (e.g. mowing of embankments or, if necessary, selective mowing to reduce the presence of undesirable species or cupping cuts to control quality). For the site management of a cattail area (maintenance, control effort, electricity requirements for pumps and maintenance), Schätzl et al. (2006) calculated costs of EUR 810 to 1,040 per ha*a. Wichmann et al. (2022a) assume that these assumptions may significantly underestimate the real costs and emphasize that concrete experience and data need to be derived from current and and future pilot projects. Schätzl et al. (2006) calculated harvesting costs of EUR 620 (chopped material) to EUR 1,600 (bundles). For the harvesting of reeds with special track-based technology, Wichmann (2017) calculated costs of approx. EUR 400 and EUR 420 per ha for chopped material and bales (range 115 - 1,100 EUR) and EUR 640 per ha for roof reed bundles (range 320 - 1,500 EUR).

Peat moss paludiculture (from Wichmann et al. 2022a)

Costs of ø EUR 2,700 per ha*a net production area were calculated for water management (e.g. control costs, electricity costs) regarding peat moss paludiculture in Hankhausen/Lower Saxony. In the case of crop maintenance, > 40 % of the costs were incurred by regular mowing of the peat moss production areas to suppress vascular plants and prevent their seeding. Other work included cleaning the irrigation ditches and mulching the driveways. Average annual costs of crop maintenance in the 1st rotation period (5 years) amounted to ø EUR 7,400 per ha. Harvesting from the driveway by crawler excavator with mowing bucket, including transport by tractor and dumper to the edge of the field, resulted in costs of ~ EUR 12,600 per ha. A significant reduction in costs can be expected here via development of harvesting technology that travels over the peat moss lawn. The economic viability of peat moss paludiculture on former bog grassland was calculated by Wichmann et al. (2020) with repeated harvests every 5 years and a total cultivation period of 20 years.

Wet meadows and wet pastures (wet grassland)

Management of wet meadows and wet pastures depends on the following factors:

- Area size
- Productivity
- Accessibility
- Transport distances
- Utilisation capacity of the technology
- Sward maintenance
- Stock density

Harvesting costs depend on the water level at harvest time and the harvesting technology used. On areas that dry out in the summer, harvesting may be possible using adapted conventional grassland technology, although a high impact force is required here due to the short harvesting window (e.g. wet meadows at Kummerower See, MV). Special technology is required during humid summers and in wet meadows with permanently high water levels. You may need your own technology or a service provider, depending on the size of the area. Purchasing harvesting equipment is a challenge for farms that want to convert their peatland to paludiculture. Several vehicles are required to set up a powerful harvesting chain. Cooperation with other farmers (e.g. in machinery rings) is therefore more attractive in terms of harvesting costs (Wichmann et al. 2022a). There are many different costs regarding technology acquisition. The figures in Wichmann (2017) range from around EUR 100,000 to around EUR 450,000 for track-based harvesting and transport technology. For applications under the ERDF-funded ProMoor funding guideline in Brandenburg, a table was provided to calculate the funding amount, which gave examples of investment costs for specialised technology, retrofitting and technical components[22]. Wichmann et al. (2022a) assume a total financing requirement of around EUR 400,000 in order to ensure not only biomass mowing but also biomass removal using special technology. The high level of wear and tear on the technology used (machinery and auxiliary equipment) must be taken into account. This is linked to a shortened service life, which for wet sites is stated to be approx. 2/3 of the normal service life, resulting in higher proportional machine costs (Wichmann et al. 2022a).

Tab. 2.9: Overview of management methods for wet pastures (summarised from Pfister & Oppermann 2021).

Management procedures	Costs per Scenario unfavourable/average/ favourable [EUR per ha*a]
Wet pasture with game fence[1]	787 / 870 / 771
Wet pasture with robust cattle breeds[2]	502 / 596 / 692
Wet pasture with water buffaloes[3]	921 / 921 / 921

1 The stock density is 7.1 / 9.8 / 10.2 animals per ha. Higher machine and enclosure costs were applied in the average scenario than in the favourable scenario, resulting in the highest costs.
2 The stock densities increase from the unfavourable to the favourable scenario, which means that the costs are highest in the favourable scenario.
3 The same costs were stated for all three cases because there was no data available for different costs.

Harvesting costs of between €52 and €150 per t DM were determined depending on the harvesting and transport technology used, based on a model for calculating labour times for harvesting biomass from paludiculture (Wenzel et al. 2022). The harvest is divided into individual process steps (Fig. 2.13). Pfister & Oppermann (2021) have calculated various scenarios for the procedural costs of wet

22 https://www.ilb.de/media/dokumente/dokumente-fuer-programme/dokumente-mit-programmzuordnung/infrastruktur/02-zuschuesse/ilb_formular_kalkulation_zuschuss_w1902220919.xlsx

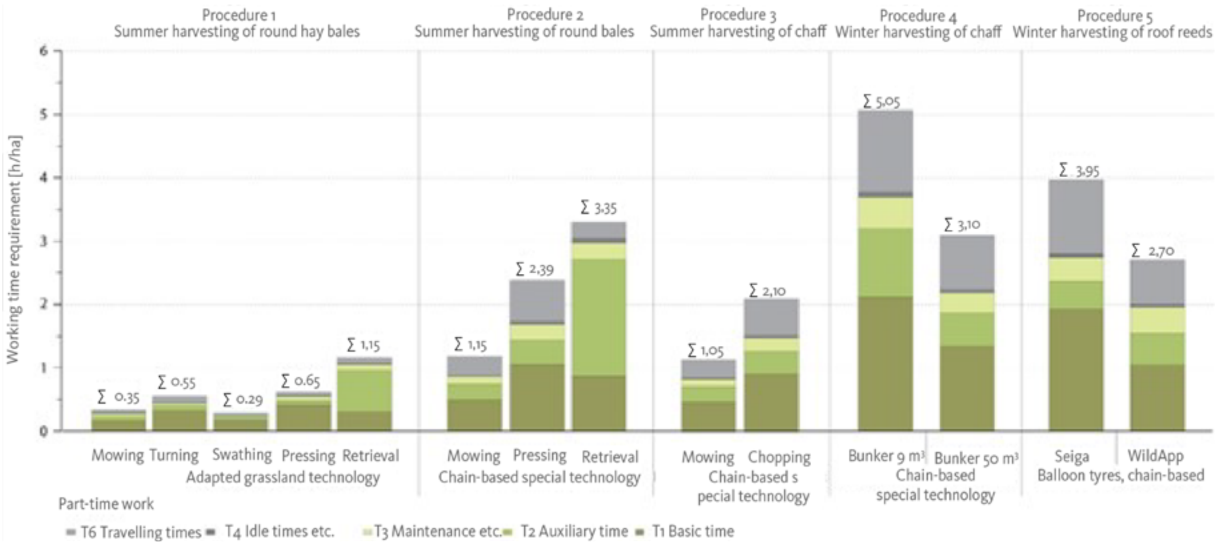


Fig. 2.13: Results of the model calculation for labour requirements during summer and winter harvest of 4 ha with a biomass productivity of 4 t DM per ha. Methods 1 - 4 represent different harvesting methods (from Wenzel et al. 2022, supplemented according to Dahms et al. 2017).

pasture management, which in turn are based on the "Faustzahlen der Landwirtschaft" (KTBL 2018) figures, the KTBL data collection "Landschaftspflege 2005" (KTBL 2005) as well as cost estimates for robust cattle breeds (Kaphengst et al. 2005) and for water buffalo (Sweers et al. 2014) and were each given for an unfavourable, average and favourable case (Tab. 2.9).

The cost factors taken into account by Pfister & Oppermann (2021), which were set at different costs or labour hours per hectare in the scenarios (unfavourable - medium - favourable), include costs per labour hour, annual fencing costs, costs for animal, drink and fence monitoring, water and feed costs, veterinary costs and slaughter costs.
The following additional (non-exhaustive) cost factors may also need to be taken into account: costs for supplementing the live stock, variable machinery costs (e.g. for re-mowing), marketing costs, interest claims, contributions and insurance.

Black Alder

Alongside the ongoing administrative costs, the alder paludiculture does not incur any annual costs for cultivation and management of the areas, but regular thinning is necessary. Initial costs are incurred for young growth maintenance 8 years after establishment of the crop. Costs of such interventions are given by Wichmann et al. (2022a) at around EUR 250 - 350 per ha for a total of four maintenance measures. They are partially eligible for subsidies in some federal states. Subsequent thinnings already provide usable wood assortments with which the costs can be covered (Schäfer & Joosten 2005).
Further costs for alder value wood production, as well as revenues, will only arise in the future, after 50 - 60 years at the end of the rotation period. Harvesting costs are rather high compared to other forestry production methods, as the wet sites can only be driven on to a limited extent and special soil-conserving harvesting technology, such as cable crane technology or track vehicle technology, must be used (Sündermann et al. 2013).

3. Utilisation of biomass from paludiculture

Paludiculture plants have developed specific characteristics to adapt to the moist and wet conditions in the peatland. For example, these include aeration tissue (aerenchyma) in the leaves and stems of the cattail, which enables the plant to transport air into the plant parts under water, or storage of silicates in various paludiculture plants, which have an anti-fungal and flame-resistant effect. Peat moss acts like a sponge and can store many times its own weight in water. These special properties of wetland plants can be used in products from paludicultures and offer advantages over typical products. Wetlands are also considered to be the most productive ecosystems on earth. Up to 20 tonnes of DM per ha*a of biomass can be harvested with a sufficient supply of nutrients and water. Products made from renewable raw materials due to paludiculture can also achieve a climate protection effect by a factor of two or three (e.g. Tanneberger et al. 2020, Nordt & Dahms 2021, Lahtinen et al. 2022), namely by:

1. reduction in emissions due to the increase in water levels in the production area,
2. determination of carbon in the (durable) product, and
3. replacement of fossil raw materials.

Paludiculture crops generally replace existing raw materials, substitution of which should be followed if a better carbon footprint can be achieved.

The product's low carbon footprint could lead to a market advantage and thus increase the demand for paludiculture raw materials (Doderer et al. 2016, Nordt & Doderer 2017).

Chapter 3 provides an overview of the possible usage pathways paths for raw materials and products from the management of wet and rewetted peatlands. It is essential that functioning, economically viable production lines are developed in the medium term for the large-scale establishment of paludiculture. There are currently a large number of promising product prototypes, but few established products made from paludiculture raw materials on the market. Table 3.1 provides an overview of the suitability and practical effectiveness of various production lines.

Tab. 3.1 Practical effectiveness (+ or ++) and suitability (colour-coded) of crop and wet meadow paludicultures for various uses. Practical effectiveness: + = prototypes or test facilities or areas available, ++ = already implemented on a larger scale; suitability: green = high potential, ochre = limited potential: technical adaptation/development necessary or suitable only for niche use, no colour = unsuitable or unknown potential. This overview is based on an expert assessment and reflects the current status (as of 2022).

Culture/Biomass	Peat moss	Sundew	Reeds	Cattail	Reed canary grass	Alder	Wet meadows
Animal-bound uses			+	+	++		++
Biogas wet fermentation			+	+	+		++
Biogas dry fermentation					+		++
Combustion			+		++	+	++
Construction and insulating materials			++	+	+	+	+
Panel material (furniture)			+	+	+	++	+
Paper, moulded parts			+	+	+		+
Platform chemicals			+	+	+		+
Organic and activated carbon			+		+		+
Substrates and soils	++		+	+			+
Medical applications		+					
Phytomining					+		+

3.1 Utilisation options

3.1.1 Animal-bound uses

Use of biomass "via the animal's stomach" is an established agricultural practice. Rewetted peatland sites are largely no longer suitable for the production of fodder for (intensive) dairy cattle use, as the fodder values of the wetland plants are insufficient. However, there are possibilities for grazing with adapted animals and utilising the growth as roughage, bedding or extracting proteins for the production of animal feed.

Grazing

Grazing with robust breeds and water buffalo, which are adapted to moist and wet conditions as well as forage rich in crude fibre, offers an opportunity to continue or adapt existing forms of management. In some cases, existing farm equipment can continue to be used (stables, etc.).

Grazing is often carried out with the aim of maintaining the landscape and keeping it open. There are various contractual nature conservation programmes as well as agri-environmental and climate programmes in the federal states for this purpose (see Chapter 6), without which meat production on peatland cannot compete with fattening on other sites. Table 3.10 provides an overview of the revenue potential from marketing. As well as meat production, milk production with water buffalo on wet land is more of a niche as the associated labour costs are very high. **Water buffaloes** are ready for slaughter at around 20 - 30 months and the slaughter yield is 55 % of the live weight. Water buffalo have a thicker skullcap and slaughterhouses must be equipped accordingly (Birr et al. 2021). Pasture shooting is an alternative in some federal states.

In Germany, the buffalo population is estimated at more than 6,000 animals[23] , trending upwards. In comparison: The cattle population in Germany will total 11.18 million cattle in 2021, of which around 4 million will be dairy cows. Over 3 million cattle are slaughtered in Germany every year[24]. The rearing and marketing of water buffalo for meat is currently primarily linked to landscape conservation and is a niche use, but may gain in importance and represent an animal-based transitional solution for the use of wet meadows. Alongside the marketing of meat, there is currently also a demand for breeding animals to build up herds.

The meat from water buffalo is usually marketed directly, whereby the increased labour required for direct marketing is also offset by higher revenues. Revenue for the meat is roughly on a par with organically produced beef. The profit of water buffalo farming on wet fen sites is between -132 and 838 EUR per ha*a (Birr et al. 2021).

In addition to water buffaloes, **robust cattle breeds** with low weights are suitable for grazing wet grassland to produce meat (Birr et al. 2021). These include Aberdeen Angus, Dexter, Fjäll, Galloway, Heck, Highland, Hinterwald and Murnau-Werdenfels cattle. Care should be taken to

Fig. 3.1: Water buffalo in the rewetted coastal flooding marsh at Karrendorfer Wiesen, near Greifswald. Landscape conservationists are successfully pushing back the reeds. Photo: S. Abel

23 www.deutschlandfunkkultur.de/wasserbueffel-in-deutschland-exotische-heimkehrer-100.html
24 de.statista.com/statistik/daten/studie/459147/umfrage/rinderschlachtungen-in-deutschland/

Tab. 3.2: Overview of animal-based usage options (grazing, feed production) with paludiculture
1 based on Birr et al. 2021

Animal-bound use				
	Paludiculture	**Harvest time/ utilisation period**	**Product**	**Marketing**
Grazing with water buffalo or robust cattle[1]	Wet pasture, young reeds; focus on maintenance/ landscape management	All year round, stock density 0.8 - 1.5 LU per ha	Meat, Breading animals, Landscape management	Primarily direct marketing
Agricultural fencing (deer, horses)[1]	Wet and moist pasture	All year round, stock density 0.5 - 1 LU per ha	Meat, Landscape Management, Therapy with horses	Primarily direct marketing (game)
Pasture with geese, sheep[1]	moist pasture: no paludiculture	Rotational grazing, stock density 0.8 - 1.5 LU per ha	Meat, Landscape management	
Roughage for suckler cows/ young cattle	Hay from wet and moist meadows	1st and possibly 2nd cut	Meat	Existing/established material flows
Horse hay	Hay from wet and moist meadows (including reed canary grass)	Second or late cut		Existing market
Feed for dairy cattle	(fresh and ensiled) cattail	Summer harvest	Milk	Reduced carbon footprint[25] of milk production (on peatland)
Protein-containing feed for pigs and chickens	Pressed juice from biorefinery processes and material fibre utilisation (e.g. cattail, reed canary grass)	Summer harvest	Meat	Established marketing
Bedding	Reed canary grass, sedges and other wet meadow grasses	Late cut in summer	Optional further use of the litter in biogas plants/organic fertiliser	Replacement of straw (pellets) as bedding

25 The carbon footprint of a product covers the GHG emissions generated throughout the entire life cycle of a product (upstream chains, production, use, disposal, transport). Milk from drained peatland has a carbon footprint approx. 5 times larger than milk from mineral soils.

ensure that the wet areas are fenced off at the beginning of the growing season, as the forage value decreases rapidly over the course of the year (Müller & Sweers 2016).

There are farms in Germany that already have experience with grazing on wet sites. Practical tips on pasture management can also be provided by associations or clubs:

- The NaturWeiden Donaumoos association focuses on near-natural grazing in the Swabian Donaumoos: www.naturweidendonaumoos.de
- ABU – Arbeitsgemeinschaft Biologischer Umweltschutz im Kreis Soest e.V. has developed a practical guide for year-round grazing in nature conservation and landscape development called "Wilde Weiden (Wild Pastures)".
- Bunzel-Drüke et al. (2019): Naturnahe Beweidung und Natura 2000 (Near-natural grazing and Natura 2000).
- The Bunde Wischen association manages land belonging to the Landestiftung S-H state foundation and has extensive expertise regarding grazing animals and locations: www.bundewischen.de

Year-round **farming** of red deer or horses (Exmoor and Icelandic ponies, Konik) is possible on rewetted fens where there are also dry/mineral areas as retreats. The minimum area size is 2 ha (Birr et al. 2021). Reeds, sedges, overgrown grass (horses) and shrubs (deer) are also eaten. Supplementary feeding with hay is necessary in winter.

Grazing with **geese** can be carried out between one- or two-furrow mowing cycles. The long fattening period lasts 28 - 32 weeks. Selected breeds can make good use of green and fibrous feed with a low nutrient content, but need sufficient sweet grasses. Goose farming is profitable from around 1,000 animals upwards, which requires at least 20 ha of land (Birr et al. 2021).

Grazing with robust land sheep is only possible in areas bordering on paludiculture (wet meadows). Regional **sheep breeds** that are adapted to the respective climatic conditions should be used, but only on moist sites, i.e. with water levels in summer averaging 20 - 45 cm below ground level (slightly peat-depleting). Economic viability essentially depends on the income from landscape management and on the seasonal fluctuations in income from lambs (Birr et al. 2021). Subsequent mowing is advisable due to selective grazing.

Overall, grazing quickly reaches its limits with peat-preserving water levels. Grazing periods are short, highly dependent on the weather and can fail completely in some years. There is also a higher risk of infestation with parasites and hoof diseases. In the light of the uncertain future facing land-based animal husbandry, even on better sites, grazing in paludiculture is more of a niche and is also limited to the transition areas to drier soils.

Roughage

Grass cuttings from wet meadows are used in suckler cow husbandry, heifer fattening and as horse feed. The structure-rich hay is also popular in small animal husbandry, but the quantities available are limited. Quality is determined by the species composition as well as the time of harvest and has a corresponding effect on suitability. Work is also currently underway on new seed mixtures with moisture-tolerant species to improve feed quality for suckler cows[26]. A (niche) market is created by "speciality feeds" such as horse treats made from hay pellets, for which several euros are paid per kg, but which have a limited market scope. Late-harvested reed canary grass hay is well suited as horse feed: It has a fructan content of >5 % and can be fed in larger daily quantities without exceeding the daily requirement of digestible protein (Zielke 2016). Marketing and sale of hay to horse owners takes place nationwide in some cases. Prices fluctuate and depend on the weather conditions in any given year as well as the associated scarcity or good availability of hay. Revenue potential is shown in Table 3.10. Field drying is difficult in wet meadows with high summer groundwater levels.

Cattail as fodder

Silage and forage trials of cattail with dry dairy cattle were successful in the Netherlands (2017/2018) (Pijlmann et al. 2019). Initial trials clearly showed that the feed value of cattail is lower than that of grass. Grass silage was also preferred to cattail silage by the cows and cattail is more difficult to ensile than grass. Fresh young cattail plants were more readily accepted by the cows than preserved cattail. Cattail has a high selenium content, meaning that additional administration of selenium is not necessary or can be reduced. Feeding cattail to dairy cattle resulted in an 8 - 10 % reduction in milk yield. This can be compensated for by increasing the amount of concentrated feed (pers. comm. C. Fritz 2021). Cattail is therefore not suitable as fodder for high-performance cattle.

Extraction of proteins for animal feed production

Proteins can be extracted from "green" fen biomass harvested in summer using a “green” biorefinery process. The concentrated pressed juice can be fed to monogastric animals, e.g. chickens and pigs, thus reducing the import of proteins for meat production. The protein press juice is a by-product of bio-refining, and the extracted plant substances lignin, hemicellulose and cellulose can also be used to process platform chemicals, bioenergy, proteins for food and fibre products from the extracted fibre components (see below). When reed canary grass was used twice a year, up to 2.2 tonnes of DM per ha*a of protein concentrate could be refined, with a crude protein content of up to 39 % (Nielsen et al. 2021). However, information on the contents of lysine and methionine as important amino acids for pig feed within biorefinery of paludiculture grasses is still lacking (pers. comm. C. Nielsen, M. Götz 2021). The first commercial production facilities exist in Denmark (DLG 2020) and Germany, but without a focus on paludiculture biomass.

Biorefinery proteins can already represent an alternative for organic pig farmers. In Germany, organic pork accounted for approx. 1% of total pork production in 2019 (approx. 30,900 tonnes) and organic poultry for approx. 2% of total poultry meat production (26,390 tonnes), and the trend is rising in both cases (BÖLW 2021). Approximately 3.8 million tonnes of soya were imported into Germany for animal feed purposes in 2018/2019, of which approx. 65,000 tonnes were organic soya (Deutscher Bundestag 2020, Frühschutz 2020).

26 https://www.lfl.bayern.de/iab/kulturlandschaft/262620/index.php

Bedding

Growths from wet meadows are absorbent just like other grass-like growths. As an example, wet meadow hay can only be used to a limited extent as bedding for cattle, horses, chickens or pigs due to its susceptibility to mould during the time-consuming and often unsafe field drying process. Subsequent use in a biogas plant or as organic fertiliser is possible. Practical trials are currently being carried out in dairy cattle and horse husbandry in Sweden with briquetted and chopped hay made from reed canary grass[27] . Subsequent use of the litter in a biogas plant on the dairy farm in question led to increased biogas production. There was an increased amount of dust in parts of the utilisation process, meaning that technical adjustments are necessary.

Pelletising to produce bedding is also possible. It increases transportability and storage density. Pellets are largely germ-free due to heating during pelletisation. There is a lack of practical experience to date. For comparable litter straw pellets such as those used for poultry farming, the end customer price is around EUR 0.3 per kg[28] . Bedding pellets can also be further utilised in the biogas plant in the cascade. It is possible to pelletise wet meadow hay, which costs around EUR 100 - 150 per tonne (Dahms et al. 2017, pers. comm. F. Havemeyer 2021).

The use of wet meadow hay as bedding is currently mainly due to a lack of alternatives with higher added value.

Additional information:

- Birr et al. (2021): Zukunftsfähige Land- und Forstwirtschaft auf Niedermooren – Steckbriefe für klimaschonende, biodiversitätsfördernde Bewirtschaftungsverfahren (Sustainable agriculture and forestry on fens - profiles for environmentally friendly cultivation methods that encourage biodiversity).
- Närmann et al. (Hrsg., 2021): Klimaschonende, biodiversitätsfördernde Bewirtschaftung von Niedermoorböden (Environmentally friendly cultivation of fens that encourages biodiversity). BfN-Skript 616.
- KTBL (2010): Planungsdaten für die Haltung von Wasserbüffeln (Planning data for keeping water buffaloes).
- Dahms et al. (2017): Paludi-Pellets-Broschüre (Paludi pellets brochure). Halmgutartige Festbrennstoffe aus nassen Mooren (Stalk-type solid fuels from wet peatlands).
- Zahn, A. (2014): Beweidung von feuchtem, nährstoffreichem Offenland (Grazing on wet, nutrient-rich open country). – In: Burkart-Aicher, B. et al., Online-Handbuch "Beweidung im Naturschutz", Akademie für Naturschutz und Landschaftspflege (ANL), Laufen (Online manual "Grazing in nature conservation); www.anl.bayern.de/fachinformationen/beweidung/handbuchinhalt.htm
- www.hutelandschaft-rodachaue.de

27 www.go-grass.eu
28 www.strohpellets-strohgranulat.de/strohpellets/

3.1.2 Energy use

Cuttings from wet peatlands will be used as a raw material for direct thermal utilisation for (electricity and) heat production. Greater added value can possibly be achieved by refining the biomass into liquid and gaseous biofuels. An overview can be found at Table 3.3.

Biogas (and potential cascades)

In principle, biomass from paludicultures such as cattails, reeds, reed canary grass and sedges can deliver similar biogas yields to grass silage in wet fermentation. An early cut is fundamental for this (Dragoni et al. 2017, Hartung et al. 2020, Roj-Rojewski et al. 2019). Previous investigations in batch fermentation tests show methane yields for biomass from paludiculture in the average range, with some significant differences between different plant species. The methane yields were 102 – 240 L_N per kg_{oTM} or biogas yields between 311 – 581 L_N per kg_{oTM} with average methane contents in the biogas of 54 – 60 % (Eller et al. 2020, Roj-Rojewski et al. 2019, Hartung et al. 2020). The biogas yield decreases with increasing plant age as the proportion of biomass that is difficult or impossible to ferment (e.g. lignin) increases (Czubaszek et al. 2021).

Tab. 3.3: Overview of the energy application options for paludiculture biomass.

Energy use				
Product/ Process	**Paludiculture**	**Harvest time/ utilisation period**	**Product**	**Application potential**
Biogas / wet fermentation	Wet meadows, reed canary grass, sedges; pressed juice from material utilisation processes	Summer	Electricity, heat, processed biogas	depending on basic conditions, among other things: Post-EEG plants, CO_2 pricing of fuel, research and development
Biogas / dry fermentation	Wet meadows	Second or late cut	Heat	Coupling to heat sink necessary, subsequent material utilisation of the fermentation substrate possible (e.g. substrate)
Fuel, direct combustion	Reeds, hay from wet meadows, reed canary grass, sedges	Late cutting (dependent on "hay weather"), winter harvest (reeds)	Heat	Heating plant - connection to heat sink and heat network required
Electricity / Photovoltaics	Wet meadow, wet pasture	all year round	Current	Agri/open space PV
Coal / pyrolysis	Wet meadow, reeds	Summer, autumn, winter harvest	Heat, plant and activated	Soil conditioner, filter, feed additive, etc.

This increases the dry matter content in the fermenter, leading to an increased load on the agitators - and therefore also to higher electricity costs. In conventionally operated biogas plants (based on maize silage), a paludiculture biomass share of up to 20 % appears feasible. If necessary, degradability of the material can be increased by preparatory processing, e.g. using a hammer mill (Hartung et al. 2020, Eller et al. 2020). The energy input required for processing must be taken into account.

Existing plants that already use grass as a substrate could switch to reed canary grass. By-products from other processes, such as pressed juice from biorefinery processes, can be used to improve the methane yield.

As fresh biomass is only available during the harvesting period, conserving it is necessary. The ensiling of biomass from paludicultures has so far only been tested in isolated cases and yielded varying results. Biomass must be easily compactable for this, and a sugar-rich ensiling partner may be required (Herrmann et al. 2014). Removing the fresh, i.e. heavy, material from the surface at high water levels is challenging and time-consuming.

In solid matter fermentation (dry fermentation), lignified stalk-type biomass (hay and silage) can be used for fermentation. The fermentation material remains in the fermenter for around 3 weeks. Stackable fermentation material is fed in discontinuously using a wheel loader. The airtight substrate is sprinkled with percolate in the fermenter, which is collected and reintroduced for humidification. Part of the digestate serves as a starter culture for new fermentation material (Carius 2020). The digestate can be applied as organic fertiliser or used in a cascade for further use of fibres, possibly via compaction for incineration, carbonisation, as bedding or as an additive for substrates. There are still hardly any established processes in practice, as solid matter fermentation is not widespread and has logistical capacity limits. In addition, a connected heat sink is required and regional utilisation structures are needed for the digestate.

Fig. 3.2: Agrotherm GmbH heating plant in Malchin, where biomass from a rewetted fen is burnt. Photos: T. Dahms.

Production of biogas with biomass from paludiculture is highly questionable. The gas yield of hay from drained, extensively used peatland sites is only about half that of maize, yet with double the harvesting costs. As harvesting biomass in wet peatland is even more cost-intensive, biogas production from paludiculture biomass has so far only appeared to be ecologically and economically feasible as part of a cascade utilisation process.

There may be future potential from old plants that are released from EEG subsidisation and switching from maize silage to other input materials, as well as from demand for "vegan" biogas, which is processed and fed into the gas grid. The conversion to wet meadow biomass is being examined for initial systems (pers. comm. B. Spanjers 2021). Whether this makes ecological sense remains questionable in view of the low gas yield and high harvesting costs. A carbon footprint assessment is not yet available.

Additional information:

- Stiller & Ohl (2015): Untersuchung zur Feststoffvergärung von Landschaftspflegematerial niedersächsischer Grünlandstandorte (Investigation in dry fermentation of material from landscape management in grassland sites within Lower Saxony).
- Carius et al. (2011): Effizienzsteigerung von Grünlandsubstraten in der Biogasgewinnung unter Berücksichtigung naturschutzfachlicher Belange (Increasing efficiency of grassland substrates in biogas production taking environmental concerns into account).
- Scholwin & Siegert (2020). Biogas aus Paludikulturen – Produktionsweg, Hintergründe, Klimaschutzwirkung. (Biogas from paludicultures - production method, background, effects on climate protection).
- Nordt et al. (2020): Machbarkeitsstudie Aufwuchsverwertung und Artenvielfalt in der Leader-Region „Kulturlandschaften Osterholz“, (Feasibility study for the use of growth and biodiversity in the “Kulturlandschaften Osterholz” leader region) p. 112ff.

Combustion

Production of heat and hot water by burning the (dry) growth of wet meadows has been established by Agrotherm at the Malchin/M-V site since 2014 (Fig. 3.2). Around 3,500 MWh of heat are generated here each year, with the fuel being harvested in the form of hay bales from around 300 hectares of wet meadows in late summer. The combustion technology for straw is established and can be used for wet meadow hay with a few technical amendments (Meier 2014). Additional costs are incurred if the fuel is contaminated (e.g. by floating debris brought in by flooding) and due to the risk of slagging in the boiler. The proportion of ash is less than 10 % of the fuel (Wenzel et al. 2022) and can be reused as fertiliser or must be disposed of (for a fee) (Schröder et al. 2017). Availability of a sufficiently large (ideally year-round) heat sink, e.g. existing (municipal) heating networks, industrial plants or the combination with biomass drying in summer, is key to ensuring that the plant is utilised as much as possible throughout the year. One challenge lies in the production of dry, storable fuel on wet peatland, especially in years with very high summer water levels, when soil drying is not possible or when the timeframes for haymaking are too short. Alternatively, a second fuel source and supply to the boiler should be taken into consideration in technical terms, such as pourable wood chippings or pellets. Heat generation costs largely consist of the investment and operating costs; if the fuel is compacted then pelletisation costs are also added (Dahms et al. 2017). Fuel costs are largely determined by harvesting costs.

Combustion of wet meadow biomass can be economically viable under locally favourable conditions. Heat supply costs are between 60 - 75 € per MWh, whereby the fuel costs for stalk-type biomass from wet peatlands are stable in the long term and are not subject to the price volatility of fossil fuels (Wenzel et al. 2022).

Additional information:

- Dahms et al. (2017): Paludi-Pellets-Broschüre (Paludi pellets brochure). Halmgutartige Festbrennstoffe aus nassen Mooren (Stalk-type solid fuels from wet peatlands)
- Wenzel et al. (2022): Bioenergie aus nassen Mooren -Thermische Verwertung von halmgutartiger Biomasse aus Paludikultur (Bioenergy from wet peatlands - thermal utilisation of stalk-type biomass derived from paludiculture).
- Malchin heating plant - Agrotherm GmbH: http://www.niedermoor-nutzen.de/
- Nordt et al. (2020): Machbarkeitsstudie Aufwuchsverwertung und Artenvielfalt in der Leader-Region „Kulturlandschaften Osterholz“, (Feasibility study for the use of growth and biodiversity in the “Kulturlandschaften Osterholz” leader region) p. 106ff.
- Schröder et al. (2017): Entwicklung einer klimagerechten regionalen Energieversorgung durch Paludikultur am Beispiel des Landkreises Vorpommern-Rügen (Development of an environmentally friendly, regional energy supply via paludiculture using an example from the Western Pomerania-Rügen region)

Fig. 3.3: Solarpark Lottorf ground-mounted PV system from Wattmanufactur in partially rewetted peatland in Schleswig-Holstein. Photo: Bas Spanjers.

Photovoltaics on rewetted peatland

The necessary expansion of renewable energy also draws attention to generation of renewable electricity with ground-mounted photovoltaic (PV) systems and agri-PV systems on agricultural land. On peatland sites, this is often associated with the expectation that a PV system can increase yields per hectare. Heavily degraded peat soils should be prioritised for testing/utilisation in this case. It is also essential that installation of a system does not prevent or impair rewetting, or that it takes place directly in connection with installation of the system (Fig. 3.3). Otherwise, high surface GHG emissions from peatland drainage may be fixed in the long term, while construction of a PV system serves to reduce emissions (in the energy sector). The foundation or anchoring of the support structure in the ground represents a challenge when erecting systems, as this must either be carried out in the mineral subsoil - which is difficult with peat thicknesses of up to several metres - or via sufficiently stable foundations, which must be installed into the peat body. Use of heavy equipment leads to (further) soil compaction and possibly to irreversible damage to the peat body; new solutions must therefore be developed. Alignment and spacing of the modules must be put together in such a way that sufficient light reaches the ground for the plants to grow, as plant ground cover is necessary to protect the peat body. Further findings on the effects of PV systems on typical peatland biodiversity, peat conservation and the long-term technical requirements for PV systems as well as on dismantling issues are currently lacking and are urgently needed in order to be able to make recommendations and regulations for construction of new systems on peatland sites.

Agri-PV systems do not yet offer the option of harvesting and further utilising paludiculture biomass. Since paludiculture requires agricultural or forestry use, PV systems cannot be labelled as paludiculture.

Additional information on PV:

- GMC (2022): Informationspapier des Greifswald Moor Centrum zu Photovoltaik-Anlagen auf Moorböden (Information paper from Greifswald Mire Centre on photovoltaic systems on peat soils)
- Fraunhofer Institute for Solar Energy Systems (2022): Agri-Photovoltaik: (Agri-photovoltaics: Chance für Landwirtschaft und Energiewende. (An opportunity for agriculture and the energy revolution) Ein Leitfaden für Deutschland (A guide for Germany).
- BMWK, BMUW & BMEL (2022): Ausbau der Photovoltaik auf Freiflächen im Einklang mit landwirtschaftlicher Nutzung und Naturschutz. (Expansion of photovoltaics on open spaces in harmony with agricultural use and nature conservation.) Eckpunktepapier (position paper).

Carbonisation (pyrolysis or hydrothermal carbonisation)

Carbonisation of biomass can be used to produce carbons that can be used in many different ways in the medium term. During pyrolysis, dry biomass (at least 65 % dry matter) - such as hay or wood - is carbonised in the absence of oxygen and at very high temperatures. In hydrothermal carbonisation (HTC), moist biomass (e.g. digestate from the biogas plant) is converted into a carbon-containing solid using heat and pressure. Depending on process control, carbon can be produced with different properties, e.g. as a soil conditioner, as a feed additive to improve animal health and reduce odours in stables, as activated carbon to act as a filter for municipal wastewater, as a building material additive (e.g. in concrete) or as an electrode material in energy storage systems. The carbon can also be bound in the long term, depending on the application of the coal. Alongside using the carbon produced, the process heat from pyrolysis can be fed to a heat sink or used to generate electricity via a combined heat and power plant. Carbonisation systems in various sizes are already available on the market.

Biochar and activated carbons obtained from grass-like source materials by thermal conversion could represent an alternative to conventionally produced activated carbons in the future (da Silva Veiga et al. 2020, Awasthi et al. 2019). At the moment, these are mainly produced in Asia from hard coal, lignite and coconut shells with negative environmental impacts and also transported over long distances (Joseph et al. 2020). With further expansion of wastewater treatment plants for the removal of trace substances, the annual demand for Germany, Austria and Switzerland can be estimated at 41,000 tonnes of activated carbon. Costs per tonne are around EUR 1,300 - 1,500 per tonne. However, rising costs are to be expected here due to increases in demand and the CO_2 tax. The price of activated carbon can be several euros per kg.[29]

The suitability of paludiculture biomass for carbonisation has not yet been specifically investigated. However, the low bulk material density imposes logistical limits on carbonisation and restricts large-scale utilisation. Other substitutes also appear more promising. Application of both processes in Germany is currently focussed on residual materials ("waste") as source material, such as agricultural residues, digestates, sewage sludge, food waste, etc. Achievable revenues for growth from rewetted peatlands as a source material for carbonisation are therefore estimated to be low - at least at present.

The production and use of biochar as a negative emissions technology (PyCCS = pyrogenic carbon capture and storage) may gain importance due to the possibility of long-term and stable carbon sequestration.

Additional information:

- Go Grass project: https://www.go-grass.eu/germany/
- Fachverband Pflanzenkohle (Biochar trade association): https://fachverbandpflanzenkohle.org/
- Europäisches Pfanzenkohle Industrie Konsortium (European Biochar Industry Consortium): https://www.biochar-industry.com/

29 https://em-sued.de/pflanzenkohle-allgaeu

3.1.3 Construction, insulating and other materials

Use of raw materials derived from paludiculture in the form of construction, insulation and other materials shows high application potential with medium to high revenue options in the short to medium term. Tab. 3.4 provides an overview of existing applications.

Tab. 3.4: Overview of building and insulation materials made from paludiculture biomass (Fig. 3.3 – 3.12).
1 Birr et al. 2021

Material utilisation: Construction and insulating materials				
Product	**Paludiculture**	**Harvest time/ utilisation period**	**Application**	**Application readiness**
Reed bundles/ roof reed	Reed	Winter	Thatching	Established on the market
Various reed panels made from reed stalks	Reed	Winter	Insulation material, plaster base, acoustic elements	Established on the market
Cattail sheet material	Cattail (leaves, stems)	Autumn/winter harvest	Building and insulation board	Application tested, raw material missing
Cavity insulation	Cattail (whole plant), wet meadow biomass	Autumn/winter harvest	Insulation material	Application tested with prototypes, raw material missing (cattail)
Grass fibre mats	wet meadow biomass	Summer, late cutting	Insulation material	Product available, only partial use of paludiculture raw materials until now
Cellulose foam boards	Sedges, reed canary grass, reeds, cattails	Late summer/ autumn	Insulation material	Prototypes manufactured under laboratory conditions, no product yet
Fibre material panels	Wet meadow biomass, reeds, cattails	Summer, winter	Furniture construction, various panel materials	Prototypes produced
Plywood, solid wood[1]	Alder	Thinning for plywood, solid wood after 60-80 years, in autumn/winter	Worktops, furniture	Available on the market

Grass-like paludiculture plants have specific properties that make them of interest for the construction, insulation and materials sectors: some paludiculture plants are naturally antifungal and have developed stable, strong structures to stand up to several metres high in some cases as well as withstanding the impact of waves on bodies of water, as well as an airy tissue structure in the leaves and stems to channel air into the roots (aerenchyma).

The structural properties of plants are specifically used in construction and insulation products made from **crop paludicultures such as reed and cattail**. The required quality of raw material is adapted to the respective product requirements via establishment, crop management during cultivation and suitable harvest times. The best-known products include thatched roofs and insulation boards, cattail insulation boards and cavity insulation. The plant components are used in their entirety, e.g. the whole stalks in reed bundles for roof covering. Alternatively, they can be shredded, e.g. TyphaBoard with cut cattail leaves that are glued together or cavity insulation made from shredded whole cattail plants.

Building and insulating materials made from reed have traditionally been used for thousands of years. The most common use is thatching (reed). The reed stalks are also used to make insulation panels that are bound with wire. They are available in various thicknesses. The straws are also bound into privacy screens and fences, fixed tightly to a base board as acoustic absorber elements or sold individually processed as drinking straws.

There is an established market for reed products, for which over 80 % of the raw material currently has to be imported (Wichmann & Köbbing 2015; Becker et al. 2020), as there is not enough harvested or cultivated area available in Germany. To date, reed cutting for roof reed in Germany has taken place within natural reedbeds in Germany, for which the reed cutters require temporary permits from the respective nature conservation or environmental authorities (GMC et al. 2019). However, there is a high demand for regionally produced reeds. To handle the volume of the whole market (approx. 3 million bundles) of roof reed in Germany, the area required for reed paludiculture is estimated at max. 10,000 ha (Becker et al. 2020). Cultivation of reeds has been and is being tested in various trials, and there is a need for research on reed quality and yield depending on site conditions.

Cattail cultivation has so far only taken place on a few trial plots, which means that there are not yet sufficient quantities of raw materials available for development of downstream processing capacities. Promising building and insulating materials made from cattail are currently only available as prototypes and in small-scale production (e.g. TyphaBoard from typha technik Naturbaustoffe and the Fraunhofer Institute for Building Physics IBP). The costly certification and authorisation of cattail products will also only take place once cultivation areas have been established and there is sufficient security of supply.

Using more complex processing methods, heterogeneous biomass from harvesting **wet meadow grasses** can also be processed into building and insulation materials as well as other materials. Depending on the application, the biomass is processed to a greater degree - for example, shredded, pressed, defibered and thus modified mechanically, chemically or by adding heat and pressure in order to achieve the desired product requirements. Paludiculture biomass can (prospectively) be integrated into existing utilisation processes that have not been developed specifically for paludiculture, but in which grass-like biomass can be processed. If necessary, (technical) adjustments must be made to the special features of paludiculture biomass or the harvested biomass must be pre-processed. Possible products include: Grass fibre insulation mats, cellulose cavity insulation materials, cellulose foam boards, fibreboard panels for furniture or interior fittings as well as other board materials, e.g. for the automotive industry from interior panelling to mat materials for sound insulation and as upholstery material. These raw materials can also be used as a filler for mixed crops with high-performance components. Use of secondary raw materials is also important, i.e. residues, e.g. after fibre processing, which can be fed into other cascades.

Characteristics of individual paludiculture insulation materials in terms of thermal conductivity and bulk density are summarised at Table 3.5. The values are essentially comparable with other insulation materials made from renewable raw materials.

Fig. 3.3: Reed insulation board. Photo: Hiss-Reet

Fig. 3.4: Roof reed for thatching. Photo: F. Tanneberger

Fig. 3.5: Grass fibre insulation mats from Gramiterm. Photo: A. Nordt

Fig. 3.6: Construction and insulation board made from cattail (TyphaBoard). Photo: typha-technik.

Abb. 3.7: Fibre composite panel made from wet meadow biomass. Manufactured by ZELFO Technology. Photo: S. Manzel

Fig. 3.8: Combined cabinet/staircase element made of grass-fibre composite panels in the Paludi Tiny House from Moor-and-more.

Fig. 3.9: Acoustic elements made of reed stems from HISS-Reet. Photo: A. Nordt.

Fig. 3.10: Prototype of a foam panel made from sedge biomass. Manufactured by Fraunhofer Institute for Wood Research, WKI. Photo: S. Manzel

Fig. 3.11: Test with cattail cavity insulation. Photo: W. Wichtmann.

Fig. 3.12: Cavity insulation material made from cattail biomass. Photo: W. Wichtmann

Tab. 3.5: Characteristic values of various insulation materials (prototypes and products) made from or with raw materials derived from paludiculture (Source: GMC 2022b: Steckbriefe „Produkte aus Paludikultur“ (Profiles “Products from paludiculture”))

Product	Application	Thermal conductivity [W/(m*K)]	Bulk density [kg/m³]
Reed panel	Interior insulation, interior fittings Plaster base Interior/exterior/roof insulation Insulation/sound/plaster base board	0,065 0,059 0,061 0,055	145 190–220 155
TyphaBoard cattail plate	Interior/roof/sound insulation	0,040 0,048–0,060	
Cavity insulation	Insulation	0,040	80–90
Insulation mats	Grass: Interior/exterior/roof insulation	0,041	40
Foam boards	Insulation material	0,037–0,040	65–97

The market share of insulation materials made from renewable raw materials (RRM) was 9% in Germany in 2019. This trend is rising. It corresponds to a quantity of 3.5 million cubic metres. RRM insulation materials were used as cavity insulation and mat insulation, each accounting for just under a quarter, and more than half in the form of board insulation[30]. On the other hand, around 18.5 million m³ (48 %) of insulation materials made from fossil raw materials were sold in Germany in 2019, as well as a further 16.5 million m³ (43 %) of insulation materials made from mineral raw materials. Based on annual insulation material requirements of 38.5 million m³ in Germany, a theoretical area requirement of about 385,000 ha would produce insulation materials from paludiculture with a market share of 10%. This illustrates the high area potential for this usage option.

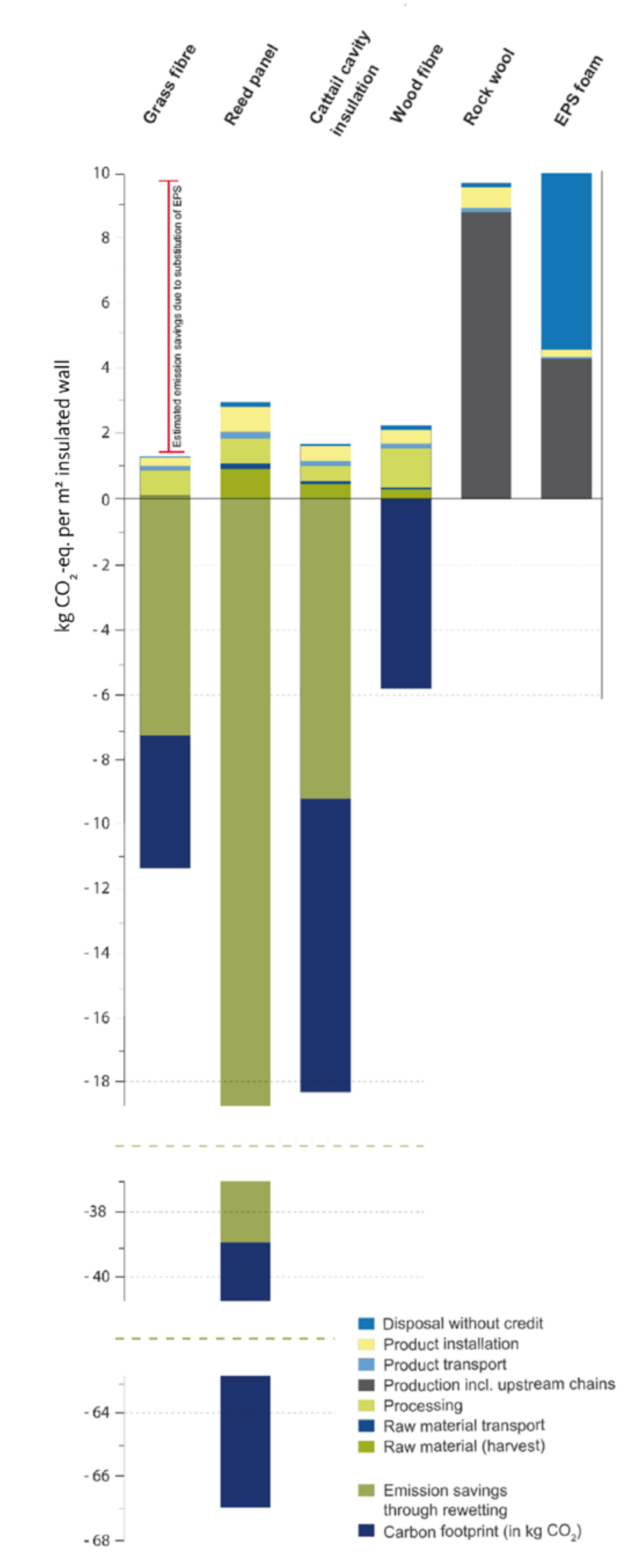
If the low or even negative carbon footprint of paludiculture insulation materials were credited to the product, this would lead to a market advantage and could increase the demand for paludiculture raw materials (Nordt & Dahms 2021; see Box 3.1). For example, the carbon footprint of building and insulation materials could be used as a selection criterion for materials to be used in (public) construction projects and would thus have a positive signalling effect both for raw material producers, i.e. farmers, and for the development of processing capacities.

A substantial increase in demand for building and insulation materials from paludiculture will only occur when products are created from prototypes and these are professionalised, namely when all the characteristic values are available for the product and for components. This makes the products accessible to architecture and planning offices without much additional effort.

30 https://news.fnr.de/fnr-pressemitteilung/marktanteil-von-nawaro-daemmstoffen-waechst

Box 3.1 *Carbon footprint of insulation materials from paludiculture*

(according to Nordt & Dahms 2021)



The illustration shows a comparison of the carbon footprint of soft fibre boards made from grass, reed boards made from bound reed stalks and cavity insulation made from cattail chaff with wood fibre insulation, rock wool and EPS rigid foam for wall and roof insulation. The comparison is based on a 1 m² insulated wall as a functional unit.

Data regarding the GHG emissions of wood fibre insulation, rock wool and EPS rigid foam are taken from the respective environmental product declarations of the individual products. For insulation materials from paludiculture, emission factors were used for the rewetting of organic soils as well as the direct emissions from harvesting, transport, processing, installation and end-of-life treatment were estimated. While incineration of a product at the end of its life is usually recognised as a credit (i.e. emission savings by replacing fossil fuels), this was not taken into account here. The reason for this is that the product lifespan extends beyond 2050 and Germany will be carbon-neutral by then. Fossil fuels will therefore no longer used and can no longer be replaced. The calculated determination of carbon in the long-life products is based on the respective carbon content of the paludiculture biomass and the weight.

This estimate shows the potential for climate-friendly insulation materials based on biomass from wet peatlands. Replacing rock wool or EPS foam leads to GHG savings of up to ~8.5 kg CO_2 per square metre of insulated wall. The carbon storage in the paludiculture products is similar to GHG savings through substitution (4 to 9 kg CO_2 per square metre of insulated wall). It is an order of magnitude higher (28 kg CO_2 per m² wall) with the reed panel due to the high biomass input. The reduction in GHG emissions through rewetting depends on the quantity of biomass in the product and the productivity of the site. Insulation materials from paludiculture reduce CO_2 emissions by between 7 and almost 39 kg per square metre of insulated wall.

The amount of CO_2 stored in durable products from paludiculture is almost as high as the reduction in CO_2 emissions through rewetting. The reed and cattail insulation materials analysed consist of (almost) 100 % biomass and comprise low processing intensity.

The raw material price for roof reed and reed panels is around EUR 450 per tonne for cleaned reed. The raw material price for cattail to be used in insulation board production is around EUR 150 - 300 per tonne (Wichmann et al. 2022a). Due to global supply and transport problems, the price of reed bundles in Germany is currently more than double the average price in some cases (as of 6/2022).

Additional information:

- Wichmann et al. (2022a): Lösungsansätze zum Erreichen der Klimaschutzziele und Kosten für die Umstellung auf Paludikultur (Solutions for achieving climate protection targets and costs involved in switching to paludiculture). (Hintergrundpapier zur Studie „Anreize für Paludikultur zur Umsetzung der Klimaschutzziele 2030 und 2050") (Background paper to the study "Incentives for paludiculture as part of implementation of 2030 and 2050 climate protection targets")
- Nordt et al. (2020): Machbarkeitsstudie Aufwuchsverwertung und Artenvielfalt in der Leader-Region „Kulturlandschaften Osterholz", (Feasibility study for the use of growth and biodiversity in the "Kulturlandschaften Osterholz" leader region).
- Fraunhofer Institute for Building Physics; https://www.ibp.fraunhofer.de/de/projekte-referenzen/baustoff-aus-rohrkolben.html
- GMC (2019): Faktenpapier Rohrwerbung Mecklenburg-Vorpommern (Fact sheet on reed cutting in Mecklenburg-Western Pomerania
- 3N Paludiculture Competence Centre; https://paludikultur-niedersachsen.de/
- Paludi-PRIMA project (2019-2022) for cultivation of cattails; https://www.moorwissen.de/paludi-progress.html

3.1.4 Paper and moulded parts

Fibres from paludiculture biomass offer potential for use in paper and production of moulded pulp. Table 3.6 provides an overview of existing and prospective applications.

Tab.3.6: Overview of options for producing paper and moulded parts from paludiculture biomass.

Material utilisation: Paper and moulded parts				
Product	**Paludiculture**	**Harvest time/ utilisation period**	**Application**	**Application potential**
Paper, cardboard, carton	Wet meadow biomass (pelletised)	Summer, late cut	e.g. as transport packaging (folding boxboard)	Grass paper packaging available on the market based on meadow hay, protyotype paludiculture biomass use
Moulded pulp	Stalk-type biomass (e.g. reeds, cattails, wet meadows)	Summer, late cut	"Egg cartons", moulded parts for packaging, disposable crockery (e.g. for food to-go)	Food packaging, industrial transport packaging, disposable items in the healthcare sector

Paper, cardboard and paperboard

Pulp is the basis for the production of paper, cardboard and paperboard, and pulp is made from cellulose from plants. Over 90 % of the world's pulp is obtained from wood. However, cellulose can also be obtained from stalks such as grass, reeds and straw. The use of grass as a raw material in paper production reduces water and energy requirements by over 90 % in each case, and - in contrast to pulp production from wood - no chemicals need to be used. It is expected that raw materials from paludicultures will be used in combinations with previously utilised cellulose (pers. comm. S. Tech, 2022).

Dry biomass (hay) is shredded and compacted for processing (Fig. 3.13). As grass pellets, they can be incorporated into existing production processes during further processing. This means the grass pellets must fulfil the raw material requirements. These include the ability to dissolve within 20 minutes in the pulper, specific fibre lengths of the target fraction (0.8 - 1.2 mm for paper), the lowest possible proportion of coarse particles and particulates (max. 20 %) as well as having a low protein and sugar content. As processing is purely mechanical, all biomass content is used in the paper and cardboard production process. At this point they may have negative effects on production processes, e.g. by dissolving in the process water and increasing the effort required for water treatment (Cruse et al. 2015). The properties of the biomass can be influenced and the effects can therefore be mitigated by adapting the management of the cultivated area (e.g. during harvest time).

Reed is suitable for the paper industry as it has a high cellulose content (40 - 50 %) and long fibres (Cook et al. 1974). The fibres of reed canary grass are particularly suitable for the production of fine papers: with short, narrow fibres and a high fibre content (Finell 2003, El Bassam 2010).

Preliminary tests with excessive wet meadow grasses were promising in 2020 (pers. comm. M. Croheck in Nordt et al. 2020). The following criteria were listed for an initial assessment of the suitability of biomass for paper production (pers. comm. M. Croheck 2020): Hay bales should be as free of impurities as possible, the raw material should contain different types of grass, the moisture content should be low enough to allow storage and mould growth should be avoided, as this would have an effect on the odour of the end product. Previous tests on the use of hay as a raw material for the pulp and paper industry have shown an improvement in bending stiffness and it is therefore eminently suitable in the production of cardboard for sustainable packaging (Höller et al. 2021, Cruse et al. 2015).

The continuing trend towards online and mail order business is increasing the demand for transport packaging, which is largely made from cardboard and paperboard. Over 12.1 million tonnes of paper, cardboard and paperboard were produced in Germany for use as packaging in 2019 (FNR 2020). The total production volume was 22.1 million tonnes of paper, cardboard and paperboard, including not only packaging but also hygiene paper, graphic paper and paper for special technical applications.

In total, 5.2 million tonnes of virgin fibre or pulp (23%) and 17.1 million tonnes of waste paper (77%) were consumed for production of paper, cardboard and paperboard in Germany in 2019 (pulp and fibres, FNR 2020). The theoretical market potential for grass fibres in this production process covers the proportion of the fibre material, i.e. approx. 5 million tonnes per year. Assuming a productivity of 3 tonnes per hectare, this would require 500,000 hectares of land - if 30% of the raw materials were produced from paludiculture - which corresponds to more than a third of peatlands used for agriculture in Germany.

It would be possible to scale up the use of grass fibres in production by initially using a lower proportion of grass fibres in the end product (e.g. 10 - 20 %), which could be increased in future as experience is gained and potential technical adjustments are made. Smaller paper machines produce around 40,000 tonnes of paper, while larger machines produce up to 400,000 tonnes of paper per year. With a substitution share of 30 % of classic wood pulp with the new grass-like fibre pulp, this results in a demand of 12,000 or 120,000 tonnes per year for each plant. It is estimated that 1 tonne of fibre requires 1.25 tonnes of wet meadow hay. Regional grass pellet plants should have at least 4,000 tonnes of pellets in order to be operated cost-effectively (Cruse et al. 2015), which requires approx. 5,000 tonnes of hay. It can also make sense to connect to existing heat generation systems to enable reliable drying of hay. The raw material price for wet meadow hay is roughly based on the regional hay price and is around EUR 80 - 150 per tonne.

Fig. 3.13: Pellets from wet meadow hay could be produced decentrally and integrated into existing production processes. Photo: Michaela Meyer

Wet meadow biomass from paludiculture appears to be suitable as a raw material for grass paper. A major challenge in raw material production is field drying of biomass when groundwater levels are low in summer ("hay weather") in conjunction with the necessary security of supply so that enough raw material can be made available even in wet years.

Additional information:

- Cruse et al. (2015): Entwicklung eines Verfahrens zur Gewinnung von Gras als Rohstoff und Verarbeitung für die Herstellung von Papierprodukten unter besonderer Berücksichtigung des Aufbaus einer nachhaltigen Wertschöpfungskette (Development of a procedure for extraction of grass as a raw material and processing for production of paper products with special consideration on establishing a sustainable value chain).
- www.paludikultur-niedersachsen.de
- Dietz et al. (2014): Ersatz klassischer Faserstoffe durch biogene Reststoffe Teil 1 und Teil 2, Wochenblatt für Papierfabrikation 4/2014 und 5/2014 (allgemeiner Überblick, kein Bezug zu Paludikulturen) (Replacement of conventional fibres with biogenic residues Part 1 and Part 2, Wochenblatt Papierfabrikation 4/2014 und 5/2014 - general overview, no reference to paludicultures)

Moulded pulp/moulded parts

Pulp made from fresh and recycled fibres is also used for moulded pulp products. Some producers utilise fibrous digestates from biogas production, straw and agricultural residues. Moulded pulp products are disposable products that can be recycled and/or composted. Egg cartons and similar shock-absorbing (food) transport packaging are a typical moulded pulp product. In addition, moulded pulp packaging is increasingly being produced for the ready meals to-go sector and as disposable crockery (Fig. 3.14). The packaging can be provided with a water-resistant, grease-repellent barrier coating. In addition, moulded pulp parts are increasingly being used as packaging for electronic devices, in the light and automotive industries, agriculture and for cosmetics, replacing (EPS) packaging based on petroleum. Moulded pulp products are also used as disposable products in the clinical and healthcare sectors. Current developments are focusing on integration of new properties into moulded pulp products, e.g. to make them fire-retardant and more thermally stable (Strauss 2018).

Moulded pulp products are often marketed in connection with their ecological advantages. The first egg cartons with a grass fibre content of 50% are already being offered, although these are not the result of paludiculture. The use of stalk-type growths from rewetted peatlands can contribute to a (further) reduction in the carbon footprint of the product (see Chapter 3.1.3). However, product-related lifecycle analyses are required to quantify the savings and make them comparable. In addition, the (paludi) raw material must be processed appropriately to ensure material processing within the procedure, to exploit beneficial properties of the raw material and to remove disruptive or harmful ingredients from the raw material. It is estimated that approximately 30 % of paludiculture biomass could be used as virgin fibre in the moulded pulp process (pers. comm. S. Tech, 2022). The raw material should be free of foreign bodies and also be conveyable (bulk material). In industrial applications, tonnages of over 1,000 tonnes per year are required in order to run plants cost-effectively. The price for a tonne of (pre-processed) raw material is based on the price for recycled paper (approx. EUR 180 per tonne for sorted, mixed waste paper in Germany, +/- EUR 30 per tonne); the price for high-quality moulded pulp products, e.g. in the food contact sector, is somewhat higher.

Potential for provision of raw materials from paludiculture is estimated to be similarly high.

Fig. 3.14: Disposable crockery made from reed and cattail. Prototypes from Biolutions. Photo: S. Abel

3.1.5 Biorefinery for the production of platform chemicals and plastics

In the biorefinery, the components of the biomass are processed into various intermediate and end products (Tab. 3.7).

Biomass is broken down into cellulose components, hemicellulose and xyloses as well as lignin via component separation in the lignocellulose biorefinery. The carbohydrates are dissolved in this first process step and the xyloses are refined into furfural in a hydrothermal process (under increased pressure and temperature). Furfural is used as a basic chemical for e.g. synthetic resins in chemistry, but also for pharmaceuticals and natural substances (Türk 2014). Approx. 10 kg of furfural can be produced from 100 kg of hay. Phenol mixtures can be processed from the lignin, which are used in resins and varnishes, for example.

The cellulose and its hydrolysis products from stalk-type biomass react in an aqueous medium under hydrothermal conditions to form HMF, the bio-based chemical 5-hydroxymethylfurfural (Steinbach et al. 2017). Bio-based plastic packaging can be produced from HMF. HMF is a versatile renewable building block and, along with furfural, is one of the 12 most important bio-based platform chemicals of the future (Bozell & Petersen 2010).

The production of HMF and furfural from stalk-type biomass is technically possible, is currently at pilot plant scale (TRL 6) and is currently being scaled up further. There is no attractive market for HMF yet. Downstream chemistry, i.e. the product development of intermediates into marketable end products, is still under development (Dahmen et al. 2018). The quantities available are still too small at present. There is also work on scaling the processes here. They may be ready for the market in

Tab. 3.7: Overview of options for producing platform chemicals and plastics from paludiculture biomass

Lignocellulose biorefinery: Platform chemicals and plastics				
Product	**Paludiculture**	**Harvest time/ utilisation period**	**Application**	**Areas of application**
Proteins	Wet meadows	multi-furrow	Proteins	Pet food (see Chapter 3.1.1), food supplements
Furfural	Stalk-type paludicultures	Late cut, max. 2-furrow	Synthetic resins, platform chemicals	e.g. medicines, crop protection, polymer resins
HMF	Wet meadows, stalk-type paludicultures	Late cut, max. 2-furrow	Platform chemicals	Plastics, e.g. PEF for packaging, bottles, fibres, etc, Medication, plant protection, etc.
Lignin	Wet meadows, stalk-type paludicultures	Late cut, max. 2-furrow	Platform Aromatic monomers and oligomers	Resins, varnishes, binders, etc.

just a few years. The conceptual development includes "on-farm biorefineries", i.e. decentralised processing of raw materials where they are harvested. Implementation in an aqueous medium (green chemistry approach) enables decentralised, regional operation without major infrastructure requirements. The process is broken down into individual sub-modules. Different types of (stalk-type) biomass can be used to produce chemicals depending on the configuration. If the protein content of biomass harvested in summer is high then a protein separation module is required, as proteins can interfere with subsequent processes. Although this makes the plant somewhat more expensive to purchase and operate, the separated protein is used to produce another product that could be used as animal feed, for example (see Chapter 3.1.1). Biomass harvested later in the year (one- or two-furrow mowing), on the other hand, contains hardly any proteins. It must be dried and storable in order to ensure year-round operation of the biorefinery despite the seasonal nature of the biomass supply. So far, paludiculture biomass has only been used in laboratory tests as part of preliminary studies. These showed a similar level of suitability for the lignocellulose biorefinery. Raw material prices are based on the price of hay and range from EUR 80 - 150 per tonne.

The material prices for bio-based and biodegradable plastic products are two to three times higher than the current prices for competing petrochemical materials. Alongside process optimisation, the profitability of biorefinery concepts is influenced by the market potential of bio-based products, which, in contrast to fossil-based products, offer functional advantages through better material properties and improved sustainability (FNR 2014).

HMF can be further processed into polyethylene furanoate (PEF), a bio-based high-performance polymer with excellent physical and chemical properties compared to other polyesters such as PET (Burgess et al. 2014). PEF can be recycled by type and (for small volumes at the start of market entry) recycled together with PET.

Around 660,000 tonnes of newly produced packaging PET are traded every year in Germany alone. In future, this could be replaced by PEF, which is not yet produced on a large scale. PEF also has better mechanical properties, which means that less material needs to be used for the production of packaging. In Germany, plastic packaging has a market potential with a volume of around EUR 15 billion. Packaging films and film products account for around a third of this. Production of bioplastics worldwide amounted to around 4.2 million tonnes in 2016. 48% of bioplastics are currently used in the packaging industry. [31]

Weitere Informationen:

- Conversion Technologies of Bio-based Resources University of Hohenheim
- Bundesregierung (Hrsg., 2014): Biorefineries roadmap as part of the German government's action plans for material and energy utilisation of renewable raw materials.
- Dahmen et al. (2018): Integrated lignocellulosic value chains in a growing bioeconomy: Status quo and perspectives.
- Institute for Bioplastics and Biocomposites (2021): Biopolymers, facts and statistics 2021.

31 https://www.k-zeitung.de/marktprognose-biokunststoffe-sieht-starkes-wachstum/

3.1.6 Substrates and potting soils for horticulture

In addition to peat mosses, other paludicultures are also being investigated as peat substitutes or substrate starting materials (Tab. 3.8).

Around 8 million m³ of peat is currently extracted annually in Germany on approx. 10,000 ha, and an additional 3.7 million m³ of peat-based raw materials and substrates are imported (BMEL 2022). Approximately 52 % of the German substrate industry's products (around 4 million cubic metres) are growing media for commercial horticulture, more than half of which are used to grow vegetable crops, while 48 % (around 3.7 million cubic metres) are potting soils for hobby horticulture (BMEL 2022).

Bog peat is currently the most important raw material for horticultural substrates and potting soils. Due to peatland protection aspects and the GHG emissions released during extraction and use of peat, an intensive search for alternatives as well as development of such has been taking place for years. Political objectives, such as peat reduction strategies, confirm this. The aim is to completely dispense with peat in the hobby sector by 2026 and in commercial horticulture by 2030[32]. The current proportion of peat substitutes in potting soils for the hobby sector is 30 %, in commercial horticulture it is currently only 10 % (BMEL 2022). To date, compost (750,000 m³), wood chippings and fibres (500,000 m³), bark humus (300,000 m³) and coconut fibres (100,000 m³) have been used as organic substrate raw material in Germany to reduce the proportion of peat in growing media. Due to competition for use or high transport costs, they are only available to a limited extent or can only be used proportionally in the substrate due to the high quality requirements in commercial horticulture.

Tab. 3.8: Overview of options for producing substrate starting materials and potting soils from paludiculture biomass

Material utilisation: Substrates and potting soils				
Product	**Paludiculture**	**Harvest time/ utilisation period**	**Application**	**Application potential**
Substrate starting material in (commercial) horticulture	Peat moss	Harvest every 3 - 5 years	Source material for high-quality substrates (as a peat substitute)	Replacement of 3.5 million m³ of white peat per year; 35,000 ha area requirement
Substrate starting material/ potting soil	Wet meadow, cattail	Autumn, winter	Additive for substrate mixtures	As a peat or compost substitute
Substrates for speciality crops	Peat moss	Harvest every 3 - 5 years	Orchid cultivation, terrariums etc.	Niche market exists

32 Climate protection programme 2030

Peat mosses

Peat moss paludiculture is a suitable crop for bog sites in particular. Peat mosses (*Sphagnum spec.*) are cultivated here (see Chapter 2.2.4 and 7.2) in order to harvest the biomass and utilise it as a renewable raw material, e.g. for the production of high-quality growing media for horticulture. Peat moss biomass has similar properties to slightly decomposed peat and is therefore ideal as a substrate starting material. Slightly decomposed bog peat was also originally formed by peat mosses centuries or even thousands of years ago in natural bogs.

The suitability of peat moss biomass as a horticultural substrate has been proven repeatedly, whereby a volume proportion of 50 % in the growing medium can be replaced by peat moss biomass without loss of quality, but this can be even higher (sometimes up to 100 %) (Gaudig et al. 2018, Fig. 3.16). Bulk densities of peat moss biomass depend on the water content as well as the particle size and range between 12 - 48 g DM per litre or 31 - 283 g FM per litre (Wichmann et al. 2020).

Peat mosses are also used in their entirety or in mixtures for speciality crops such as orchids or for carnivorous plants. Currently, living peat moss biomass is harvested from natural bogs for this purpose. A total quantity of 9000 m³ of sphagnum was imported to the Netherlands, France and Germany in 2013 (Schmilewski 2017).

Peat moss biomass has a wide range of other applications, including as a dressing material, hygiene products (nappies, sanitary towels), as ornamentation and in garden design, as insulation material in the construction sector, transport and packaging material, as an absorber in the event of chemical accidents or as a water filter.

Peat mosses as seed: “Inoculation" - the spreading of peat moss starting material ("seed") - is necessary to establish new peat moss paludiculture areas. Live peat moss cuttings are scattered after stripping the degraded topsoil, creating an embankment and an irrigation system to permanently maintain water levels a few centimetres below the peat moss surface. Application of 80 m³ of peat moss seed per hectare has proved successful for rapid establishment of a newly established peat moss paludiculture area. However, seed is not available in the necessary quantities as peat mosses are protected plants and there are currently only a few peat moss paludiculture areas where seed can be harvested. Mass production of seeds in bioreactors is currently in development in order to ensure sufficient availability of pure and high-quality seeds. Assuming productivity of 3 tonnes DM per ha*a, a net cultivation area of 35,000 ha is required to completely replace the annual demand of 3 million m³ of white peat (slightly decomposed peat moss) in Germany (Wichmann et al. 2017). Highly productive peat moss provenances are selected to increase productivity and thus yields.[33]

However, the widespread use of peat moss biomass as a substrate starting material in horticulture has not yet been established for various reasons. Lack of raw materials is crucial because peat moss paludiculture is not yet being realised on a large scale. In addition, there are not yet any RAL quality assurance criteria for peat moss biomass, as there are for all established substrate constituents. Furthermore, suitable (peat-free) substrate mixtures for individual crops based on peat moss biomass are to be further developed and crop management is to be adapted.

33 http://www.mooszucht.paludikultur.de

Peat moss biomass from paludiculture is already profitable for niche markets. The current raw material price for peat moss biomass as a substrate feedstock for speciality crops such as orchids is around EUR 165 per m³, and as seed for the establishment of new paludiculture or restoration areas it is around EUR 600 - 750 per m³ (Wichmann et al. 2020). At present, peat moss biomass is more expensive than peat, for which the raw material price is around EUR 10 - 25 per cubic metre, but environmental impact costs are not factored in. Increased willingness to pay for peat-free or peat-reduced plants will make it possible to increase revenue in the future. If the end customer had a 10 % price premium for a peat-free horticultural product, peat moss biomass from paludiculture would already be competitive with peat (Wichmann et al. 2020).

Fig. 3.15: Fresh peat moss biomass. Photo: S. Wichmann

Fig. 3.16: Poinsettia in substrate consisting of 80 % peat moss biomass. Photo: A. Prager

Fen biomass for substrate production

Biomass harvested late or in winter from rewetted fens, such as cattail, reed and reed canary grass, is also being investigated as a possible peat or compost substitute - such as a replacement for black peat in seedling cultivation - and initial results are promising. The properties of defibered aboveground paludiculture biomass harvested in winter appear to be comparable to those of wood fibres and are increasingly being used as a renewable raw material in horticultural substrates. Good features of the new raw materials include a low weight by volume as well as a high air capacity. One of the challenges is the reduction of nitrogen immobilisation, which can be reduced by a composting phase (Hartung & Meinken 2021).

Biomass from different cutting times (summer, autumn, winter) and different processing methods (chopping, pulping, composting, carbonisation) were tested. Cattail harvested in summer showed elevated salt levels that exceeded RAL limits, but said levels were significantly reduced when cutting took place later (Hartung & Eickenscheidt 2018). In principle, a proportion of 20 - 50 % biomass from fens in growing media seems feasible (Hartung & Meinken 2021), but the high potential of cattail to absorb nutrients, heavy metals and herbicides during its growth phase must be taken into account (Atif & Scholz 2011, Sasmaz et al. 2008, Wilson et al. 2000). Questions that need to be clarified for use as a substrate starting material include availability and associated storage of the raw material, contamination with germinable seeds and optimisation options for processing (Gramoflor 2020; pers. comm. J. Ewert, 2021). The willingness to pay for (processed) stalk-type biomass as a peat or compost substitute is stated at EUR 10 - 25 per cubic metre ex-works if the substrate is suitable (pers. comm. J. Gramann, 2019).

Weitere Informationen:

- Amberger-Ochsenbauer & Meinken (2020): Peat and alternative substrate starting materials
- www.torfmooskultivierung.de

3.1.7 Further (special) usage options for paludiculture biomass

The following overview lists additional usage pathways paths for (special) paludicultures for which, for example, a relatively small area or raw material volume is already sufficient to serve an (existing) market. It does not claim to be exhaustive.

Tab.3.9: Overview of further usage options for paludiculture biomass

Further usage options				
Products	**Paludiculture**	**Harvest time/ utilisation period**	**Application**	**Application potential**
Medical products (phytopharmaceuticals)	Sundew	At flowering time (July/August), manual harvesting	e.g. cough syrup and lozenges for treatment of respiratory diseases	Products established, but with low potential for acceptance
Food for beneficial organisms in ecological cultivation	Cattail pollen	Summer	Food for predatory mites as a bio-insecticide in vegetable cultivation (greenhouse)	Product established, potential by-product for further cattail use
Silicon for batteries	Reeds (leaves)	Summer/autumn	Anode material in lithium-ion batteries	Very suitable, no established usage path to date
Phytomining: Germanium and other rare earths	Reed canary grass	Summer/autumn	Metalloid for the manufacture of smartphones etc.	Relevant in the future, not yet economically viable
Berries	Cranberry	Summer	Foodstuffs	Widely used product; however cultivation is not (yet) peat-preserving

Medicinal products made from sundew

Round-leaved sundew (Drosera rotundifolia) is a (protected) plant that occurs in bogs and also establishes itself as "accompanying flora" on peat moss paludiculture areas (Baranyai & Joosten 2016). Sundew is currently used as a medicinal plant for production of around 200 - 300 registered medicinal products in Europe, mainly phytopharmaceuticals and homeopathic medicines (MacKinnon 2009). The main area of application is in treatment of respiratory diseases (Babula et al. 2009). It has good potential for commercial use. The raw material (approx. 50 - 160 tonnes per year) for this has so far come almost exclusively from wild collections in Finland, South Africa and Asia. 1 kg of raw material from wild collection is traded at EUR 164 - 1,000 per kg (pers. comm. B. Baranyai). PaludiMed GmbH (Mecklenburg-Vorpommern) is the first company to trade small quantities of sundew derived from paludiculture.

The productivity of sundew on a peat moss paludiculture area is on average 3 - 40 times higher than in natural bogs. The yield (214 kg per ha fresh mass, only flowering plants) is also higher compared to natural bogs. Paludiculture cultivation offers customers procurement security along with high product quality. In order to provide the quantities of raw materials previously traded from wild collections in Central Europe from cultivated areas, sundew cultivation would have to cover an area of at least 160 - 550 ha (Baranyai et al., 2022). Cultivation of sundew within paludiculture is possible under existing species protection regulations.

Fig. 3.17: Sundew on peat mosses on the peat moss paludiculture area at Hankhauser Moor, near Bremen (see Chapter 7.2). Photo: S. Abel

Cattail pollen as food for beneficial insects in vegetable cultivation

Cattail pollen has proven its worth as food for predatory mites, which are used as beneficial insects for biological pest control as part of vegetable cultivation in greenhouses. Pollen-based feed is applied every 2 weeks at 500 g per ha to support the predatory mite population while no pests have yet appeared in the crops (Pijnakker et al. 2015). Cattail pollen is suitable for this as it is not collected by bees and retains its nutritional value for at least two weeks. Cattail pollen has so far been collected by hand in cattail stands in June during flowering time, but not yet in Germany. It is estimated that the pollen content is max. 1 % of the total biomass of a stand. The pollen must be dried and frozen quickly after harvesting in order to retain the required quality.

Nanostructured silicate from reed leaves for rechargeable batteries

Dry reed leaves contain a lot of micro- and nanostructured silicate. This can be purified, whereby the original structure is also retained during both chemical and physical treatment. This means that it can be converted into highly efficient anode material for lithium-ion batteries with comparatively little effort. Nanoporous silicon as an anode material has high application potential, as it has a much higher theoretical capacity and lower working voltage than previously used anode materials (Liu et al. 2015).

It is not known to the authors whether these research findings have yet been put into practice.

Phytomining

Plants absorb various elements from the soil, including silicate, as well as germanium and other rare earths. Germanium is concentrated in reed canary grass at 3 mg per kg of biomass. Germanium (and other rare elements) can be extracted from digestates or ash if the biomass is used to generate energy. Maximum phyto-extraction of 60 g per ha of germanium and 90 g per ha of rare earths is currently expected under optimal conditions (Wiche et al. 2021), which would correspond to a productivity of 20 tonnes DM / ha. However, productivity is lower on peatland sites (up to 13 tonnes DM / ha, see Box 2.1). From a concentration of germanium of around 10 mg per kg of biomass, it is assumed that it can be utilised commercially, or at a lower concentration if other elements can be separated in addition to germanium[34] . Germanium is a metalloid that is used in the manufacture of smartphones, infrared sensors and glass fibres, among other things. It is currently traded on the world market at around EUR 1,800 per kg (as of 2022). There are no deposits in Europe; germanium is extracted from fly ash in coal-fired power stations, among other things.

Berry crops

Possible berry-producing bog plants are cranberry (Vaccinium oxycoccus), lingonberry (Vaccinium vitis-idaea), black chokeberry (Aronia melanocarpa) as well as the lowbush blueberry (Vaccinium angustifolium, V. corymbosum) and the large cranberry (Vaccinium macrocarpon). Cultivation on organic soils is currently associated with drainage and intensive water level management, which means that high peat mineralisation rates are to be expected. Cranberries are also cultivated in rewetted bog grassland in the Netherlands – scientific studies on water levels and GHG emissions are currently underway.[35]

3.2 From the site to the product: which use is the right one?

Area-related preliminary considerations for selection and establishment of a paludiculture are explained in Chapter 4. The (regional) demand for raw materials plays a decisive role in the choice of utilisation method and paludiculture. This requires individual analysis of the regional sales opportunities for the biomass produced. The following questions should be addressed:

- Are there existing processing capacities that can or would utilise the raw material? (in your own company? In the region?) Or are there existing processing structures that could/would convert to paludiculture biomass?
- What are the requirements for the raw material and can these be met (quality/quantity/price)?
- In what form should the raw material be provided - as bales, bundles, chaff, ensiled?
- Does it need to be processed, preconditioned, if so, in what form (e.g. as pellets)?
- Can processing be carried out on the farm?
- Where and how is it stored and, if necessary, dried?

Material suitability can be analysed using standard feed value analyses as an initial step. Some of the processing companies have their own laboratories or carry out preliminary tests with small sample quantities.

In addition to existing regional customers, it may be possible for (economic) players to invest in de-

34 https://www.nationalgeographic.de/wissenschaft/2018/05/pflanzlicher-kumpel
35 https://www.thecranberrycompany.nl

velopment of new utilisation and marketing structures. These can be completely new systems or include the conversion of existing systems, processes and structures in order to integrate paludiculture biomass into existing processing operations.

As acceptance structures are often still new and indeed unknown in some cases, it is helpful or necessary for intermediaries to provide support in setting them up. For example, these can be regional transfer centres, regional development agencies, economic development agencies or the regional chambers of industry and commerce. The offices for economic development, regional innovation alliances and practical research institutions can also help identify suitable companies for (future) raw material procurement, arrange contacts or suitable investment funding as well as provide support with applications (see also Chapter 6). In the short term, i.e. within the next few years, these intermediaries will play an important role as long as raw materials from paludiculture are not (yet) known and established in common processing methods or production areas. Cooperation between farms would appear to make sense, by means of which the amount of land for raw material production and cultivation capacities can be increased to overcome the current "chicken-and-egg problem" - that supply and demand must be created simultaneously for raw materials and products derived from paludiculture (DVL 2022). Collaboration along the value chain may include the farm as a raw material producer, the processing company and/or the marketing company that uses or markets the end product. These collaborations enable transdisciplinary development of knowledge and experience, ranging from the influence of land management to the properties of the end product whilst enabling close feedback from all participants. One of the special properties of the (end) product from paludiculture is its impact on climate protection via the reduction of soil-borne CO_2 emissions which could also be commercialised.

Currently achievable revenues for raw materials from paludiculture are listed in Table 3.10. At present, these are often still below what farmers can earn with conventional agricultural products. Raw material production and biomass processing can be supported through further financing. These include programmes from the federal states as part of the second pillar of the CAP, which aims to reward the ecological benefits of paludiculture and high water retention in agriculturally utilised peatlands as well as providing investment support - both for the establishment of paludiculture, acquisition of adapted cultivation technology and/or facilities for processing the raw material (see Chapter 6).

	Yield per ha	Commodity price	Revenue per ha and year
Established markets for paludiculture biomass and comparable products			
Reed[1]			
- Roof reed	Ø 500 bundles	EUR 450 per tonne	Ø EUR 1.000
- Cleaning out/poorer quality		EUR 30 per tonne	
- Reed insulation boards/plaster base		~ EUR 450 per tonne	
Alder[2]			
- Trunk wood	2,7 – 3,2 Scm	EUR 46 – 54 per HCM	EUR 61 – 195 per ha
- Industrial / firewood	3,2 Scm	EUR 40 per HCM	EUR 86 – 122 per ha
Peat moss[3]			
- as a substitute for white peat in growing media	~ 50 to 200 m^3 per year	EUR 25 per m^3	EUR 1.250 – 5.000
- for orchid cultivation		EUR 165 per m^3	EUR 8.250 – 33.000
- as seed		EUR 750 per m^3	EUR 37.500 – 150.000
Sundew - medicinal applications			
- Wild collection[4]	0,3 kg FM	EUR 160 – 1.000 per kg FM,	EUR 48 – 300
- Mother tincture (10 litres from 1 kg raw material)[4]		EUR 265 per litre	EUR 795
- from Sphagnum farming[5]	23 – 405 kg FM	EUR 160 – 1.000 per kg FM	EUR 3.680 – 405.000
Fuel for heating plant			
- Wet meadow hay	2 – 4 tonnes DM	EUR 50 – 70 per tonne	EUR 100 – 280
- Straw (comparison)		EUR 80 – 100 per tonne	
(Co-)substrate for biogas systems			
- Wet fermentation[1]	3 – 8 tonnes DM	EUR 10 – 35 per tonne FM	Ø 100/max. EUR 600
- Solid matter fermentation	3 – 8 tonnes DM	n.a.	
Bedding			
- for sow-keeping	3 – 8 tonnes DM	< EUR 65 per tonne	max. EUR 195 – 520
- Straw (opportunity costs)		EUR 80 – 100 per tonne	
- Straw pellets (horses, poultry etc.)		approx. EUR 0,3 per kg	
Roughage from moist/wet grassland			
- Horse hay	3 – 8 tonnes DM	EUR 100 – 130	EUR 300 – 1040
Water buffalo[6] (full grazing system)	0,6 – 1,2 livestock		
- Meat		EUR 6 – 13 per kg	EUR 500 – 2.000
- Breeding animals/establishing herds		EUR 2.000 – 2.500 per animal	EUR 580 – 1.000
Robust cattle[7]	0,8 – 1,5 livestock		EUR 1.079 – 1.214
Use from pilot/test applications, prototypes and processes into which paludiculture biomass can potentially be supplied[8]			
Cattail insulation board[9]	10 – 25 t	EUR 150 – 300 per tonne	EUR 1.500 – 4.500
Cattail cavity insulation[10]	10 – 25 t	n.a.	
Cattail pollen[11]	3 – 8 kg	EUR 100 – 400 per kg	EUR 300 – 3.200
Cattail, reeds, wet meadow biomass: Disposable crockery[12]	5 – 25 t	~ EUR 50 per tonne	EUR 250 – 1.250
Wet grassland: Insulation materials made from grass[13]	3 – 8 t	low	
Wet grassland, reeds: Paper made from grass[14]	3 – 15 t	~ EUR 80 – 150 per tonne	EUR 240 – 2.250
Wet grassland: (pre-processed) fibres for packaging material[15]	3 – 8 t	~ EUR 150 – 210 per tonne	EUR 450 – 1.680
Wet grassland: Platform chemicals for bio-plastics[16]	3 – 8 t	~ EUR 80 – 150 per tonne	EUR 240 – 1.200
Wet grassland: Protein concentrate as feed[17]	up to 2,2 t TM	n.a.	
Wet grassland: Biochar/activated carbon	3 – 8 t	n.a.	

Tab. 3.10: Revenues achievable per hectare for biomass from paludiculture in established utilisation chains and utilisation methods with similar raw materials that are comparable to paludiculture biomass as well as test and pilot applications of paludiculture biomass processing. (modified according to Wichmann et al. 2022a, based on the original sources listed below the table. Values (as of 2022) may have changed due to transport difficulties for imported products, increased energy costs, etc.).

1 Wichmann 2017;
2 von Finkenstein & Gerst 2013;
3 Wichmann et al. 2020;
4 pers. comm. B. Baranyai: Prices for Drosera from wild collection 2019 in Finland: EUR 164 per kg, prices otherwise dependent on quality and origin between EUR 250 - 1,000 per kg;
5 Baranyai et al., 2022
6 Sweers & Müller 2016;
7 Birr et al. 2021, based on Pfister & Oppermann (2021);
8 Commodity prices correspond to stated willingness to pay or statements by potential customers;
9 pers. comm. S. Lamprecht, H.-J. Bullinger 2018;
10 Geurts & Fritz 2018;
11 pers. comm. A. van Weeren 2018, C. Fritz 2022, M. Wenzel 2022;
12 pers. comm. J. Reich 2019;
13 current usage of landscape management material;
14 pers. comm. M. Croheck 2020; Köbbing 2016;
15 Commodity price based on waste paper price;
16 Price roughly based on hay price;
17 Nielsen et al. (2021)

4. Site suitability criteria

This chapter provides an overview of site-specific suitability criteria for paludiculture areas, success factors and the demands of paludiculture on the site. The aim is to find out whether an area is suitable for the implementation of paludiculture, which crops are suitable for the site, which areas may be preferable and how implementation can be successful. The latter depends **equally** on legal requirements and local conditions as well as farming operations and utilisation (see Chapters 2 and 3). The focus is on site characteristics and requirements in this chapter.

Targets regarding conversion to paludiculture should be established in advance to assess the suitability of an area for paludiculture. Objectives can be:

- Climate protection
- Production of raw materials
- Nature and species conservation targets
- Rarer: Water protection, climate adaptation, flood protection

The extent to which development objectives compete with each other must be examined, checking if there are synergies or even conflicts. This applies in particular to areas that are subject to protected status or if individual protected species or biotopes are already present before rewetting (Närmann et al. 2021). Extraction of raw materials is often only the secondary objective here or is required for nature conservation reasons in order to achieve a certain vegetation structure (maintenance management). Cultivation of wet or rewetted peatlands is also understood as paludiculture provided the biomass is utilised commercially. The paludiculture maps of the federal states act as a useful guide (these are currently available for Mecklenburg-Western Pomerania in LM M-V 2017a and Brandenburg, Lower Saxony, Baden- Württemberg and Schleswig-Holstein in Nerger & Zeitz 2021; Fig. 4.1).

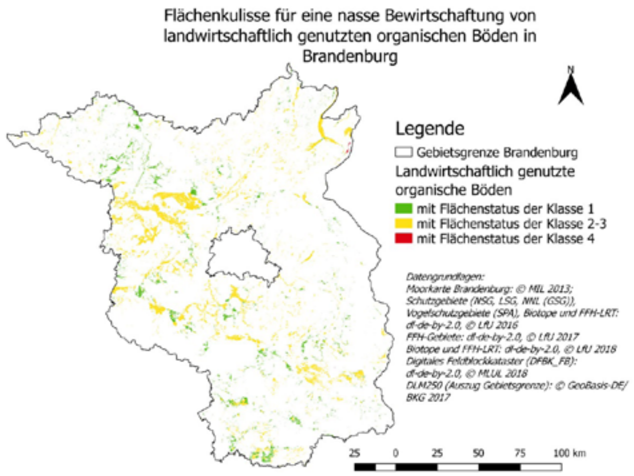


Fig. 4.1: Area map of agriculturally utilised organic soils with nature conservation assessment of suitability for wet cultivation in Brandenburg. Class 1: no nature conservation restrictions; Class 2+3: only suitable with testing requirements; Class 4: unsuitable for paludiculture. From Nerger & Zeitz 2021

For the most part, specific area assessments can be carried out by the project executor[36] themselves; for some issues, it makes sense to commission a third party (e.g. planning office) at an early stage. Alongside interviews with stakeholders, the main sources used are data from publicly accessible geoinformation services and, where applicable, the agricultural data portals of the state authorities. Other sources include state ordinances and planning documents from the municipalities as well as water and soil associations. The sources to be used are mainly state or location-specific, but most can be accessed nationwide (e.g. the state geodata portals).

If no specific areas are yet available for implementation then a deductive approach can help to identify them. Existing area maps for for paludiculture (LM M-V 2017a; Nerger & Zeitz 2021) can be used for this purpose and further suitability criteria from Chapter 4.1 can be applied to further narrow down

36 project executors are stakeholders who implement the specific measures. These can be (agricultural) businesses or mergers of businesses as well as other economically active companies, associations (e.g. water and soil associations, landscape conservation associations, nature conservation and environmental associations, etc.), regional authorities, associations, foundations, research institutions and others.

genuine implementation potential to specific peatland areas.

Further information and useful tools:

- Schlattmann & Rode (2019): The spatial potential for paludiculture: an analytical tool.
- DSS Torbos: A decision support system for peat-friendly management of organic soils (fens). See also Schulze et al. (2016)
- Tiemeyer et al. (2017): Peatland protection in Germany. BfN-Skript 462.
- Nerger & Zeitz (2021): Flächenkulisse (Area backdrop). In: Närmann et al. (Hrsg., 2021): Klimaschonende, biodiversitätsfördernde Bewirtschaftung von Niedermoorböden (Environmentally friendly cultivation of fen peatlands that encourages biodiversity). BfN-Skript 616.

4.1 Site conditions

The prerequisites for the establishment of paludiculture areas can be divided into three categories: Location properties, availability of land and technical suitability (according to Schröder et al. 2019). These prerequisites should all be met.

Location properties	Areal availability	Legal prerequisites

4.1.1 Location properties

Organic soil: A prerequisite for establishment of paludiculture is that the area under consideration is entirely or at least largely peatland or peaty soil (organic soil). In pedological terms, peatlands are defined by the presence of peat, with a thickness of at least 30 cm. If the peat layer is thinner and/or has an organic content of 15 - 30 %, it is referred to as peaty soil. As a result of drainage-based utilisation, shallow peat soils have completely or partially lost their peat layer and are then referred to as organic soils. Utilisable mapping of soil types is available in most regions and can be requested from the state offices.

Peatland type: knowledge of the hydrogenetic peatland type can be used to assess water and nutrient availability as it reflects certain location properties (Tab. 4.1). This can also be used as a criterion for assessing rewettability as it allows conclusions to be drawn about the previous water supply. Information on the type of peatland can also be obtained from the environmental authorities (e.g. peatland overview mapping for M-V, source: LUNG M-V, BÜK 50 in Lower Saxony).

Rewettability: The peatlands can either **already be wet or** it must be possible in principle to **raise the water level**. For paludiculture, peat-preserving water levels (Tab. 1.2) should be the aim. Whether the water level can be raised will be clarified during the planning process, using the indicators of water availability (climatic water balance, total runoff), water demand, nutrient supply, terrain model (relief) and drainage system to check feasibility (Schlattmann & Rode 2019, Haberl et al. 2016). A potential hydrological analysis or feasibility study should be commissioned from a planning office. At this point, further examination can take place to see if, and indeed which measures can be used to ensure that the target water levels can be achieved.

If it is not possible to achieve peat-retaining water levels for a target area then these reasons must be analysed. For example, can measures in the catchment area help to increase water availability? Are there other watering options? The highest achievable maximum summer water level should be the target in any case. The introduction of external water or construction of storage basins should not be dismissed. The additional active supply of surface water, e.g. from larger receiving water bodies, may be necessary to achieve and maintain consistently high water levels in summer (Wichtmann & Schröder 2016). If no irrigation is possible in summer then the water deficit can only be minimised by retaining winter precipitation by areal overflow of at least 30 cm above surface at the end of winter, in addition to avoiding runoff as far as possible. Cascades may be required to achieve high summer water levels across the board. It is not sufficient to only waterlog the lowest areas of a lowland; the higher fringes of valleys or the fringes of the lowland must also be included in the water retention by waterlogging. This makes realisation of paludiculture in lowland habitats very challenging. Possible variants of how to technically implement the increase in water level are described in Chapter 2.2. Another option is to set up water reservoirs as a buffer, which can be used to counterbalance increased water requirements in summer.

4.1.2 Areal availability

Implementation of paludiculture, including rewetting, can currently be seen as an encroachment on the property rights of landowners. This is due to the outdated assumption that only drained peatlands can be utilised and produce yields. Clarification is required from the authorities on whether the measure actually constitutes an intervention and therefore requires approval. Consent from the owners is currently required for the cultivation of paludiculture crops. Various preliminary considerations should be taken into account from the perspective of the owners as affected parties (Fig. 4.2).

Complicated ownership structures stand in the way of investment in the infrastructure of an area in many places. If areas in public ownership or in the ownership of the implementer are not adjacent or if there are a large number of private owners of the implementation area then this can delay or hinder implementation. However, the number of

Tab. 4.1: Suitability of different hydrogenetic peatland types for paludiculture (modified according to Haberl et al. 2016). +++ = very good, ++ = good, + = moderate, ~ = limited, - = not suitable or high technical outlay required.

Hydrogenetic peatland type	Terrestrialisation mire	Groundwater rise mire	Kettle hole mire	Flood mire	Ombrotrophic mire (bog)	Percolation mire	Sloping/ spring mire
Water supply (before drainage)	(mostly) continuous	low	periodic/ continuous	periodically	mostly continuous	continuous	continuous
Slope	none	none	none	none/ moderate	moderate (marginal)	strong	moderate - extreme
Intact internal water storage	mostly large	moderate	moderate - large	small	large	large	small
Rewettability	+++	+++	++	+++	+++	+	~
Suitability for paludiculture	++	++	-	++	+++	+	-

owners does not indicate solely the willingness to rewet (Tiemeyer et al. 2017).

Current usage rights are decisive in addition to the ownership structure. The interests of owners and users may diverge. A change of use is rendered more difficult if owners or leaseholders depend on current management. It may not be possible to implement paludiculture if the peatland on the farm in question accounts for a high proportion of the land-based value added (without taking transfer payments into account). It then needs to be clarified whether the current management on the peatland areas under consideration can be moved within the company or regionally, or whether a change in management is foreseeable. The chances of the farm being able to switch to intensification or leasing vary greatly from region to region, depending on the pressure on the land. Pressure on land also arises from manure storage areas, long-term supply contracts, e.g. with biogas plants, or long-term investments and loans, e.g. for a dairy stall, which are linked to existing drainage-based management.

If these interests cannot be brought together, there is still the option of offering a sale or exchange of land or a change/exchange of tenant. Exchange options for tenants and owners depend heavily on regional availability of equivalent or higher-quality replacement land as well as regional land pressure (Tiemeyer et al. 2017), see also Chapter 2.1. If this cannot be done by the project executors itself due to the size of the area and/or the number of owners then a land reorganisation process must be sought. Framework agreements between the users and the project executor can also help to facilitate consent, e.g. through specific regulations on damage compensation in the event of project-related rewetting damage on private land (see practical example in Chapter 7.3).

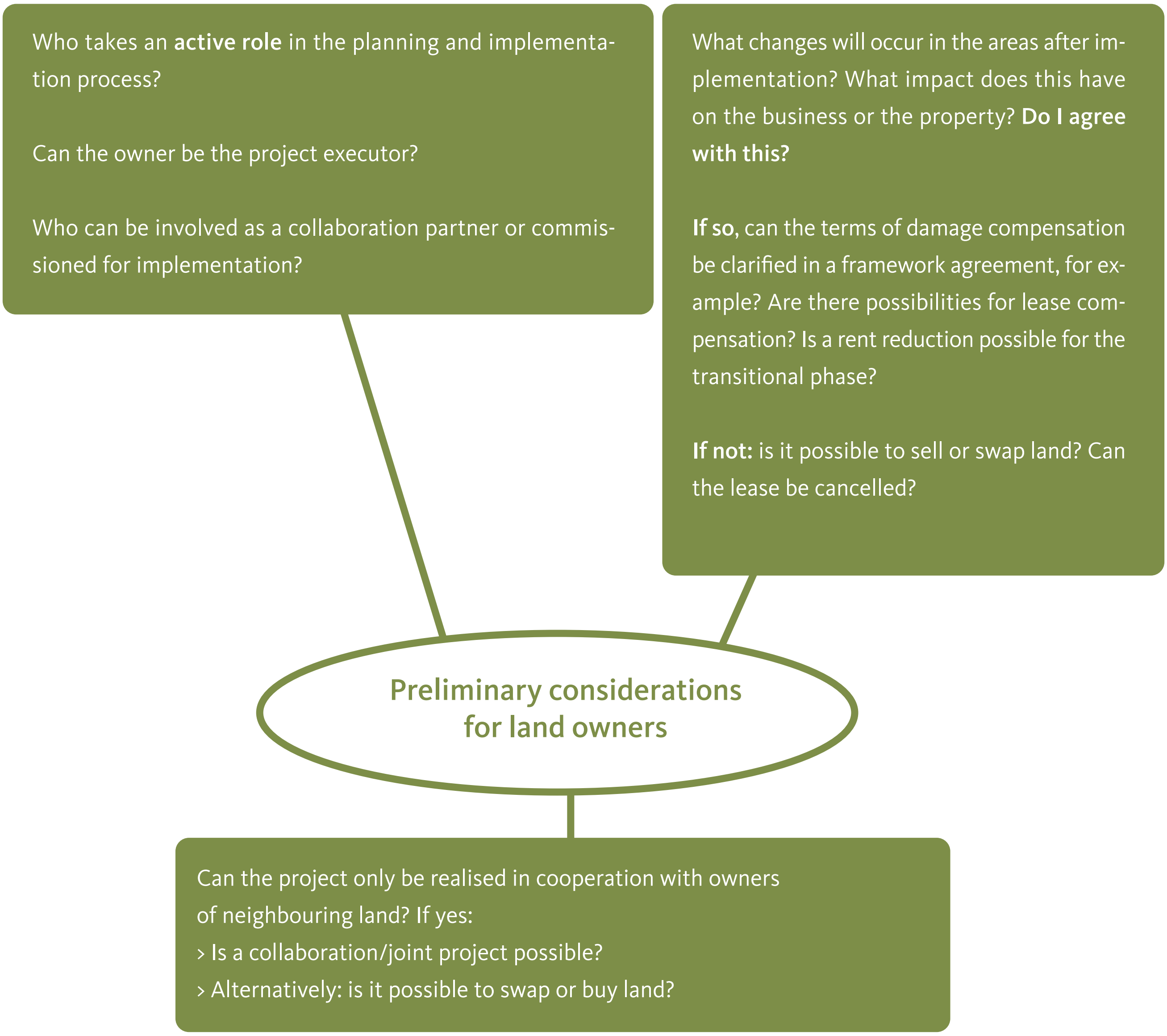


Fig. 4.2: Preliminary considerations for the implementation of rewetting and paludiculture from the perspective of the owners as affected parties or if they are initiators themselves.

4.1.3 Legal prerequisites

Nature conservation, agricultural law and other areas of law result in several framework conditions that restrict the suitability of an area or the possibilities for its use. In general: The fewer restrictions there are, the easier it is to realise a project.

Firstly, **agricultural use** must be **formally possible** on the land. This is usually the case if the area has already been used for agriculture (field block available) or if it is located in a priority or reserved area for agriculture (field block can be established). For this, the desired paludiculture must be recognised as agriculture, and new opportunities have been granted here under the CAP since 2023. Details on the recognition of paludiculture from 2023 onwards can be found in Chapter 6. The possibility of applying for agricultural support also depends on this.

The choice of the desired paludiculture must not conflict with already stated and legally binding nature conservation interests. For example, the implementation of paludiculture in core zones of protected areas in accordance with the Federal Nature Conservation Act (BNatSchG) or state nature conservation laws and the impairment of legally protected biotopes is prohibited (Section 23 (2) BNatSchG, Section 33 (1) BNatSchG, Section 30 (2) BNatSchG, Art. 6 para. 2 Habitats Directive). However, the change in use can contribute to an improvement of the protected object in the case of wet meadow paludiculture, while crop paludiculture is excluded. The paludiculture maps of the federal states of Mecklenburg-Western Pomerania (LM M-V 2017a), Brandenburg, Schleswig-Holstein and Baden-Württemberg (Nerger & Zeitz 2021) act as a starting point, and core zones of areas as well as the occurrence of biotopes can also be accessed via information services from the federal states.

Replacement habitats may have to be created in the immediate vicinity of the impact site where protected species have colonised as a result of drainage. This can be clarified by nature conservation surveys and in cooperation with the responsible local nature conservation authority. There are already examples in which it has been convincingly demonstrated that rewetting and paludiculture enhance the value of the area and that it was then possible to dispense with compensatory mitigation. Implementation of possible conditions can be costly, but at the same time the presence of certain species or habitats also offers potential synergies that can be used to finance the project. The relationship between climate protection and nature conservation goals is often ambivalent in paludiculture projects: it can be both synergetic and a source of conflict (see also Chapter 1.3.3; Chapter 5). In principle, however, an improvement for typical peatland species can be expected on deeply drained and managed peatlands by raising the water level and switching to paludiculture, meaning the change is therefore to be favoured in most cases regarding biodiversity conservation (e.g. for fens: Närmann et al. 2021).

If there are **protected features**, such as cultural monuments or archaeological sites in the project area, opinions must be obtained from the specialist authorities and external expert opinions may be required.

Incompatible or competing infrastructure or land use of public interest, such as underground pipelines, overhead lines, railway embankments, public roads, may be affected by rises in water levels. Technical solutions for compatibility may have to be considered here, or the area may not be suitable (as a whole) for the establishment of paludiculture at this point in time. This can be clarified in collaboration with the relevant authorities and specialist planning offices. Section 35(3) of the German Building Code contains a non-exhaustive list of public concerns that may prevent construction measures for a paludiculture project in an outskirt area (Schäfer & Yilmaz 2019).

The sites should be available without any formal/legal restrictions where possible, i.e. there should be **no fixed plans or objectives that are incompatible with raising water levels and paludiculture**. For example, there should be no priority areas in spatial planning whose objectives run counter to increasing water levels or agricultural use; for example, this could be the case with priority areas for raw material extraction (Tiemeyer et al. 2017). In addition, land use regulations of municipalities (e.g. land use plan, development plan) can compete with establishment of paludiculture (Schäfer & Yilmaz 2019). However, such plans and specifications can also be changed in favour of the "paludiculture capacity" of the site. This can be discussed at a preliminary meeting with the responsible authorities (see Chapter 5).

For **crop paludicultures**, possible **legal exclusion criteria for establishment and cultivation of the areas** must also be observed and applied for permission, if applicable. For example, initial ploughing up or topsoil removal usually required for establishment of a crop paludiculture on land previously managed as grassland is generally subject to authorisation and prohibited in Natura 2000 sites (Czybulka & Kölsch 2016, LM M-V 2017b, as well as for the situation in M-V: Schäfer & Yilmaz 2019), for details see Chapter 5, the section on grassland preservation). Practical examples show that exceptions are possible (as ploughing is carried out for establishment of a permanent crop, see Chapter 7.1).

Another example is the restriction of reed cutting. In M-V, for example, an exemption from statutory biotope protection (§ 20 NatSchAG M-V) is required. A revision of the so-called "reed cutting directive" in M-V is currently being discussed. For example, reed beds planted or deliberately established on field blocks could be exempt from restrictions and statutory biotope protection. There may still be federal state-specific regulations, such as the "Richtlinie zur Mahd von Schilfrohr in Röhrichten", ("Directive for cutting reeds in reedbeds" and the obligation to participate in associations (GMC 2019)). To date, licences have usually only been granted for a few years. This can also affect artificially created reed beds and possibly also other reed beds (Czybulka & Kölsch 2016), so it must be clarified with the responsible authorities before paludicultures are established.

4.2 Success factors

Once the basic requirements have been met, other less binding but desirable site characteristics should be taken into account. They point out opportunities for specific priorities or synergies within a project. The following sequence does not represent a prioritisation as this depends primarily on individual project objectives.

Areas where **water levels** can be **raised with little technical and financial effort** are particularly favourable for implementation. This is the case if:

- the area is already hydrologically delimited, e.g. by poldering (embankment),
- the polder or a depression is lower than its surroundings,
- the project area is identical to the catchment area of a ditch or pumping station,
- no adjacent areas belonging to other owners are affected,
- sufficient water is available for irrigation all year round.

The possibility of **active water regulation** should also be available or realisable. Optimum water levels for paludiculture are often difficult to realise with one-off measures. Active monitoring of water levels or an additional active supply of surface water in summer are often necessary (Wichtmann & Schröder 2016), and even essential for some paludicultures (e.g. peat moss paludiculture). Chapter 2.2 describes the necessary measures for site preparation, infrastructure, management and technology for various paludicultures.

A **favourable area size** and the **logistical infrastructure** for cultivation and utilisation are important for the economic success of paludiculture. Which size is suitable depends above all on the individual farm situation (machinery, labour force, land area, previous branches of business), the necessary harvesting, transport and storage logistics as well as existing regional utilisation structures or potential demand across the country. Collaborations (e.g. machinery rings, producer groups, cooperatives, farm coalitions - see Chapter 7.3 for the example of Biomoos GbR) can have a positive impact on profitability (DVL & GMC 2022). For most paludicultures, a sub-area should be at least ~ 10 ha in size in order to be economically viable. In most cases, however, the land requirements are much greater so that sufficient biomass can be produced for a suitable utilisation chain (exceptions are special crops such as sundew). Logistical infrastructure plays an important role in soil-conserving and effective land management. Existing access roads, (possibly raised) embankments and ditch crossings in the area, biomass handling sites at the edge of the area, storage and (covered) drying capacities all favour implementation (see Chapter 2.2).

It is often the case that initial investment for measures to raise the water level, for water management and for infrastructure on smaller areas is more complex and costly (cost per hectare) if surrounding areas continue to be drained. Although such isolated solutions are costly, they are often the only way to raise water levels and adjust them specifically to crop requirements. In many cases, subdivision of the area is necessary anyway due to the required infrastructure (road embankments, hydrological subdivision due to height differences). However, hydrological subdivision is problematic in the case of shallow, sand underlayed peatlands. At the very least, regional water storage in the near-surface groundwater needs to be optimised. A public interest in exploiting synergies with climate protection goals as well as nature conservation or water protection goals can be helpful so that even complex projects can be financed and implemented quickly.

Exploiting synergies: Revitalisation of other peatland functions and provision of ecosystem services (see Chapter 1.3.3) offer synergies with the implementation of paludicultures. These include:

- Climate protection
- Water protection (nutrient retention and nutrient removal)
- Stabilisation of the landscape water balance
- Local evaporative cooling
- Flood protection
- Educational and recreational functions

This can generate increased social benefits, or render them more visible. There is the option of valuing and valorising these additional services of paludiculture, e.g. via certificates in the future.

4.3 Site requirements of different paludicultures

The type of water supply and the quality of the water are central to an assessment of whether the peatland site is suitable for a particular paludiculture. The current condition of the site also has an impact. Knowledge of the original peatland vegetation and the former natural site conditions can also be helpful for estimating the development of the site after rewetting and for setting out guiding principles for near-natural land preparation and usage of the spontaneously growing vegetation as wet grassland. See, for example, the Leitfaden der Hochmoorrenaturierung in Bayern (Guidelines for Raised Bog Restoration in Bavaria) (2002) or the Leitfaden der Niedermoorrenaturierung (Guidelines for Fen Restoration in Bavaria) (2005), see the introduction to Chapter 2.

Near-natural peatlands naturally have a wide range of site conditions and these can be categorised using the ecological peatland types (Succow & Joosten 2001). Recent vegetation there can serve as an indicator of the nutrient content and pH value of the site. The nutrient content is roughly categorised according to the C/N value into nutrient-poor (oligotrophic, C/N 33 - 50), moderately nutrient-poor (mesotrophic, C/N: 20 - 33) and nutrient-rich (eutrophic, C/N: 10 – 20). The pH value makes it possible to categorise acidic (pH < 4.8), alkaline-rich (sub-neutral, pH 4.8 - 6.4) and calcareous (pH > 6.4) peatland sites.

Drainage, land use and fertilisation in particular have greatly changed the characteristics of the site. Recent vegetation can no longer serve as an indicator in intensive grasslands. The type of change in the soil after drainage-based utilisation depends on the type of peatland, the intensity of use as well as the duration of drainage. In general, degraded peatland soils have a greatly altered structure, which reduces the very high water storage capacity and water permeability of natural peatlands (see Chapters 1.1.3 and 2.2). The nutrient balance has also been greatly altered by fertilisation, liming and peat mineralisation. After rewetting, raised bog sites that were previously used as intensive raised bog grassland or arable land have conditions that favour nutrient-loving species. Regular harvesting results in the effects of impoverishment on all peatland sites. The nutrient supply from the mineralisation of peat is interrupted and the nutrients are mainly supplied by the water. The quality of the water therefore plays a central role in nutrient management of an area, see Chapter 2.2.3: Nutrient management. There is hardly any long-term experience in securing yields. There is still a need for research here.

Tab. 4.2: Ecological peatland types of Central Europe according to Succow & Joosten (2001).

Ecolog. peatland type	Trophy	pH	Natural vegetation	Hydrogenetic peatland type
(Acidic) peaty soil	oligotrophic	acidic	Prostrate shrub-cotton grass-peat moss lawn	bog/transition mire
Acidic transition mire	mesotrophic	acidic	Peat moss sedge meadows	bog/transition mire/fen
Alkaline transition mire	mesotrophic	weakly acidic	Brown moss sedge meadows	Fen
Limestone transition mire	mesotrophic	alkaline	Brown moss schoenus	Fen
Geogenous mire	eutrophic	acidic - alkaline	Reed beds, sedge meadows, alder swamps	Fen

Paludiculture plants can grow under a wide range of abiotic conditions and nutrient levels, but the best productivity is achieved under nutrient-rich conditions and with a balanced nutrient supply. This does not apply if certain raw material properties are achieved or species that are adapted to a low nutrient supply are cultivated, such as certain peat moss species or reeds that are particularly suitable for thatching.. Unfortunately, there is little experience currently available regarding the effects of the location on the quality aspects of the biomass (see Chapter 2; Ren et al. 2020; Haldan et al. 2022). Location requirements of the various paludicultures are shown in Table 4.3 as far as they can be narrowed down.

Further reading and sources:

- Specialised strategy/backdrops in M-V: Bericht Fachstrategie Paludikultur.pdf (Paludiculture specialised strategy report) (moorwissen.de)
- Backdrops in BB/S-H/BW: Klimaschonende, biodiversitätsfördernde Bewirtschaftung von Niedermoorböden (Environmentally friendly cultivation of fen peatlands that encourages biodiversity) (bfn.de).
- Steckbriefe Paludikultur (Paludiculture profiles): https://www.moorwissen.de/files/doc/paludikultur/imdetail/steckbriefe_pflanzenarten/Steckbriefsammlung.pdf
- Moorschutz in Deutschland – Optimierung des Moormanagements in Hinblick auf den Schutz der Biodiversität und der Ökosystemleistungen (Peatland protection in Germany - Optimisation of peatland protection regarding protection of biodiversity and ecosystem services) (thuenen.de).

Tab. 4.3: Site requirements for various paludicultures. Information on fen species derived from Birr et al. 2021 and regarding peat moss from Gaudig et al. 2018.

* There are no uniform standards for reed for thatching. Individual quality assessments (depending on the location) by reed cutters is usually based on intergenerational experience.

Paludiculture	Peatland type	Water levels and water management	Nutrient requirements	Nutrient replenishment in water	Requirement for surface homogeneity (relief, slope, etc.).)
Reed	Fens	Permanent water levels in surface, slight saltwater influence and overflow is tolerated	medium-high*	Nutrient replenishment requirements depend on utilisation, low if harvested in winter	Small-scale differences in location are tolerated
Cattail	Nutrient-rich fens	Permanently high water levels in or above the surface, saltwater influence is tolerated	(medium) high - very high	Constant replenishment required	Surfaces should be homogeneous and the water should be able to flow evenly over the surface
Wet meadow (sedge)	Fens	Water levels at or just below ground level, short-term waterlogging or lowering of water levels below ground level possible	medium	Little need for regular replenishment (with declines in yield)	Small-scale differences in location are tolerated
Reed canary grass	Alkaline-rich fens with good nutrient supply	Alternately moist to wet, oxygen-rich water; permanent overflow is not tolerated	high	Regular supply of nutrient- and oxygen-rich water via flooding necessary	Small-scale differences in location are tolerated
Peat moss	Bog	Water levels always uniform at surface level (rising with the growth of the peat mosses)	low	Natural replenishment via rainwater is sufficient	High maintenance, surfaces should be levelled; slight differences in height in the relief (approx. 20 cm) are tolerated
Black alder	Alkaline-rich fens	Moist to very moist locations with moving soil water; sensitive to prolonged flooding	high to very high	Regular replenishment of alkaline-rich water via waterlogging required	Small-scale differences in location are tolerated

5. Planning and Approval

This chapter lists the approval procedures and necessary planning steps for the establishment of a paludiculture system (crops and, if applicable, wet meadows/wet pastures) in Germany, which might differ in other countries. Central coordination should be used for the coordination of planning and approval, for which sufficient personnel capacity must be available. The requirements for official approval can vary greatly depending on the respective project components and the need for constructional adaptation. The adaptation of water management facilities and the use of water rights, the renovation or establishment of infrastructure (paths, storage areas, etc.), and change of use and nature conservation issues, need to be reviewed and planned in accordance with the legal requirements. The approval requirement results from expected effects of the measures.

Water law

For the implementation of paludiculture, it is usually necessary to raise the water level by means of water retention and, in some cases, supplying additional water from a neighboring watercourse. It needs to be clarified whether a permit is required under water law. A permit under German water law is always required if water bodies are used (see § 6 WHG), including, according to §9 WHG "...the withdrawal and discharge of water from surface waters, ... the retaining and lowering of surface waters". Furthermore, a water law procedure is required for approval if raising the water level has an impact on protected assets and/or the property rights of third parties are affected. In many cases, binding requirements for water retention are in place. In some cases, due to topographical height loses, these requirements are already sufficient for raising the water level . If it is necessary to raise the water level beyond this, a temporary **permit** can be issued **under water law**. It can be granted with the consent of the owners and users/tenants, provided that there is no direct impact on adjacent areas or infrastructure.

If water retention will result in large-scale rewetting of agricultural land, it can be assumed that the project will require **planning permission**, or **planning approval** if it will have a major impact. The approval procedure is initiated by the relevant authority once all the necessary documents have been submitted. Complete and transparent documents that meet the technical and legal requirements of the approval procedure are crucial. Table 5.1 provides a general, non-exhaustive overview of the applicable approval procedures. The type of procedure must always be agreed with the relevant authority. Therefore, at the beginning of a project:

1. identify the owners of the area under consideration and inform them of the planned change in the condition of the area. The users must also be identified and informed.
2. hold a kick-off meeting with the water authority in charge to present the planned project. Depending on the estimated scope, effects and impacts of the project, the authority determines the extent to which planning documents and expert opinions need to be submitted. These may also include, for example, species protection reports and FFH (preliminary) impact assessments, depending on whether impacts on protected assets are expected. The responsible water and soil association or maintenance association should also be involved at an early stage.

A **building permit** is required if physical structures are to be erected. The building permit is usually issued as part of the water law procedure. Whether and to what extent planning permission is required depends on the planned measures, the respective state law and the approval authority. For example, for the establishment of the cattail paludiculture in Neukalen (Mecklenburg-West Pomera-

Tab. 5.1: Overview of water law approval procedures, requirements and necessary documents.

Procedure	Required if	Required documents	Comment
No procedure required or nature conservation approval	• No third-party property rights affected, and/or • Agreement has been reached with owners and/or • Watercourses are not dedicated / no 1st and 2nd/3rd order watercourses affected • Project area is located in a protected area	• At least draft and approval planning (service phase 3+4) • Nature conservation reports (species protection, FFH (pre) compatibility) • Written consent of the owners	• Nature conservation and spatial planning aspects need to be examined separately (by the authority)
Permit under water law	• For dedicated watercourses (2nd/3rd order) • For temporary raise of water level (damming) • For planned water withdrawal • Only a few owners	• Consent of owners • Draft and approval planning (service phase 3+4)	• For uncomplicated construction procedures and projects with minor impacts (no upstream residents, etc.) • Involvement of public interest groups is decided by the water authority depending on the situation/impact
Water law approval / plan approval	• There is no obligation to carry out an EIA • For dedicated watercourses • Larger number of owners, upstream residents, etc. and/or several protected assets are affected	• Draft and approval planning (service phase 3+4) • Hydraulic / hydrogeological analysis • Subsoil survey for construction of physical structures • Nature conservation reports (species protection, FFH (pre) compatibility) • Consent of owners • Expert opinion on impacts, if applicable • Water framework regulation technical contribution	• Statements from other authorities may be required • Authority decides without public participation, no consideration possible • Involvement of public interest groups (associations, etc.) depending on impact
Planning permission	• If project is subject to EIA according to WHG • For projects with rather complex impacts (e.g. agriculture, infrastructure, residential areas) • If third-party rights could be affected (e.g. not all owners are known)	• Draft and approval planning (service phase 3+4) • Hydraulic / hydrogeological analysis • Subsoil survey for construction of physical structures • Nature conservation reports (species protection, FFH (preliminary) compatibility) • Expert opinion on impacts • Water framework regulation technical contribution	• Has bundling character, authority can weigh up and decide in the interest of common welfare • Participation of all affected parties, relevant authorities and the public required

nia, Paludi-PRIMA project), a building permit was only required for the installation of solar modules, whereas in Hankhausen near Oldenburg (Lower Saxony), a simplified procedure was required for the establishment of the peat moss paludiculture (see project examples in sections 7.1 and 7.2).

Planning steps

The planning represents the target state compared to the initial state, which qualitatively and quantitatively shows the impact on owners, users and third parties. The individual measures and their effects are presented and the costs are determined. The planning is carried out by specialist planners.

In service phase 2, the preliminary planning is created, which includes the consideration of water availability, soil analysis, assessment of feasibility, examination of ownership structure and includes the possibility of examining different variants. Hydraulic / hydrogeological surveys may be necessary to determine the impacts.

In service phase 3, the selected variant is planned in draft form and the costs for the measures are calculated. Based on the design, the planning is carried out in detail in service phase 4, including the type of physical structures, access routes and time planning for implementation. The results of service phase 4 are submitted to the authorities for approval. In service phase 3 + 4, specific investigations are also carried out if they are required by the approval authority, e.g.

- FFH preliminary assessment, an FFH impact assessment may be necessary (e.g. if a Natura 2000 protected area is located within the impact area of the paludiculture project),
- EIA preliminary assessment, environmental impact assessment may be necessary.
- Landscape management support plan (application of the impact regulation under nature conservation law),
- If necessary, species protection report (possible impact on specially or strictly protected species).

Accompanying public relations work is also useful. Particularly in the case of larger projects, the project should be presented to owners, users and residents at an early stage and they should be regularly informed about the process (information events, excursions, press, information letters, display board, etc.).

Agricultural law / Special permits required

Various special regulations may be relevant for the implementation of paludiculture. Applications for special permits or exemptions are currently often necessary in Germany.

Grassland preservation

The establishment of paludiculture crops on existing permanent grassland represents a conversion of permanent grassland into a permanent crop. It is subject to the requirements for grassland preservation based on a ratio of permanent grassland in relation to agricultural area. To date, this has generally required the establishment of a new grassland area as compensation (GMC & DVL 2021). This results from agricultural subsidy law (Regulations on CAP Direct Payments) as well as water and nature conservation law requirements (Federal Water Act, Federal Nature Conservation Act) and state law requirements in some federal states (Mecklenburg-West Pomerania, Schleswig-Holstein, Lower Saxony, Bavaria) (GMC & DVL 2021). It is important to contact and involve the responsible ministry or agricultural and environmental authority at an early stage in order to avoid compensation measures if possible.

In Germany, general exemptions already exist (case-by-case decisions, e.g. due to public interest), however further special regulations or exemptions are also necessary. This applies to the requirements for grassland preservation under the conditionality, primarily GAEC 1 "Maintenance of permanent grassland" as well as GAEC 2 "Protection of wetland and peatland" and GAEC 9 "Ban on converting or ploughing permanent grasslands in Natura 2000 sites". Exceptions to these requirements are regulated by German national implementation in the GAPKondG and the more detailed GAPKondV statutory order. According to § 12 GAPKondV, the conversion or ploughing of permanent grassland is permitted in peatlands, provided that a site-adapted wet use in the sense of a paludiculture is established. Excluded are specific grassland areas relevant to nature conservation.

Reed cutting

For the mowing of existing reedbeds, an exemption from the statutory biotope protection (e.g. § 20 NatSchAG M-V) must be applied for, whereby the "Regulation for the mowing of reed in reedbeds" (LM M-V 2000) needs to be considered and participation of an association (§ 30 NatSchAG M-V) must take place. Permits are only issued for a few years and must then be reapplied for. A revision of the so-called "reed mowing regulation" in Mecklenburg-West Pomerania is currently being field-tested. For example, reed beds planted on field blocks or established by shifting from summer to winter mowing could be exempt from restrictions and statutory biotope protection.

6. Support

6.1 Financing options in Germany

The financial requirements can be divided into one-off costs for the conversion to paludiculture and ongoing costs. One-off investment costs are usually incurred for land preparation and establishment of paludiculture, including raising the water level and setting up the utilisation and marketing of paludiculture raw materials and products. Land maintenance and harvesting, as well as water management, are annually recurring expenses (see Chapter 2.4, Fig. 6.1).

Various instruments can be combined for financing. Public funding programs for investment and innovation promotion in agriculture, and for the integration of nature conservation and climate protection into agricultural production, can address the transition of use. The conversion of drained peatland meadows into wet meadows can also be achieved under certain circumstances via the intervention and compensation regulations (direct compensation, eco-accounts). However, the focus here is on nature conservation. Taking future yields into account, private investors and financing through credits also play an important role. Similar support programs exist for the processing industries. The running costs can be covered by agri-environmental and climate schemes (AECS) which compensate for the higher expenses compared to drainage-based peatland use and are justified by the ecosystem services achieved. Ecosystem services can also be remunerated through the marketing of certificates, area- or product-related, via the private market. When combining different types of financing, e.g. funding for land purchase and rewetting and participation in AECS, the risk of double funding must be checked and excluded. Possible financing options for the various steps in the implementation of paludiculture are presented below.

Paludiculture will be eligible for subsidies under the 1st pillar of the CAP from 2023 (Wichmann et al. 2022a, see below). In all peatland-rich federal states, AECS for peatland protection are offered via the 2nd pillar or other peatland protection programs offered via state funds (see 6.1.2). Examples of the use of various instruments to finance paludiculture projects that have already been implemented can be found in Chapter 7.

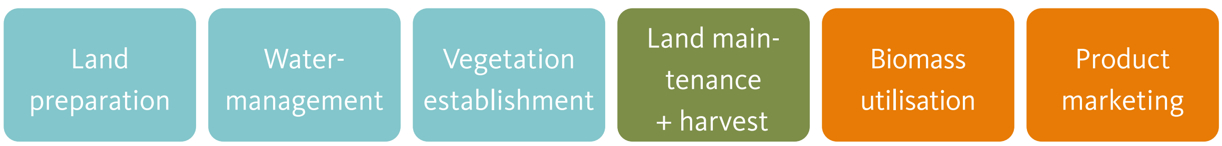


Fig. 6.1: Distinction between the various fields with financing requirements. Blue - mainly area-related financing, green - farm-related support requirements, orange - financing requirements for downstream processing and marketing of (intermediate) products.

6.1.1 Financing options for the establishment of paludicultures

The establishment of paludiculture requires investment in various cost items (Tab. 6.1, Chapter 2.4). Not all of the components shown are necessarily incurred in individual cases. Project executors are actors who implement the specific measures. These can be (agricultural) enterprises or associations of enterprises as well as other economically active companies, associations (e.g. water-soil associations, landscape conservation associations, nature conservation and environmental associations, etc.), local authorities, associations, foundations, research institutions and others. The specific funding guidelines, programmes, calls and announcements, specify the respective eligible recipients. As the amount, focus, funding areas and modalities change regularly, only a brief overview is provided below and reference is made to the relevant knowledge providers for up-to-date information - e.g. state offices, funding institutions, consultants. Private funds are provided, for example, by foundations, donations and certificates. In some cases, the project sponsors have to make their own contributions, or these are partial subsidies for investments.

Through public funding programmes for projects and investments and via private financing options, agricultural or processing companies and associations or other project executors can receive financial support for the implementation of paludiculture. The EU, the federal government and the federal states, fund public programmes.

Various agricultural and structural funding programmes are available at European level. In addition to the European Agricultural Fund (EAFRD) and the European Regional Development Fund (ERDF), the EU offers the financial instrument for the environment (LIFE), the local and regional action programmes LEADER and INTERREG, as well as a budget for the implementation of the EU Water Framework Directive (WFD).

Examples of peatland-specific offers from the ERDF for investments in peatland protection and paludiculture in the former CAP funding period 2014-2022 are the "ProMoor" programme in Brandenburg[38] and "Climate protection through peatland development" in Lower Saxony[39]. In the CAP funding period 2023-2027 several programmes are developed and will be presented below (Chapter 6.1.2).

Federal funds, e.g. from the Climate and Transformation Fund (KTF), are used to support measures as part of the Climate Action Programme 2030. An initial EUR 56 million per year was to be spent on peatland protection and reducing the use of peat in horticulture in the period 2021 - 2023, and this amount is to be increased in perspective by 2030 (Hirschelmann et al. 2020). Calls for funding within this framework are made, for example, via the Agency for Renewable Resources (FNR)[40] or by other project sponsors. In spring 2022, the Federal Ministry for the Environment presented the Natural Climate Protection Action Programme, which includes a funding programme of around EUR 4 billion for the years 2022 - 2026. Rewetting and support for agricultural businesses in the "introduction of adapted farming methods and their value creation" are key aspects of the action programme (BMUV 2022), i.e. via the NABO funding to support investments for machinery and equipment to strengthen natural soil functions in agricultural landscapes.

38 https://www.ilb.de/de/pdf/richtlinie_633602.pdf
39 https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Europa___International/efre_moorentwicklung_bf.pdf
40 FNR058-MuD-Moorbodenschutz-160921.pdf

Tab. 6.1: Overview of cost components, cost bearer and financing options for land preparation, setting up water management and establishing paludicultures (modified from Schäfer 2016 and Wichmann et al. 2022a). Gray - non-area-specific expenses for preparatory, accompanying and follow-up work in connection with water level raising and land preparation.

1 Project executors are institutions that prepare and implement peatland (climate) protection projects, e.g. (special purpose-) associations, water and soil associations, public institutions and (special purpose-) enterprises, land agencies and land companies, foundations, agricultural enterprises, etc.

Cost components	**Cost bearer / sponsor**	**Financing options**
Coordination and communication	Project executor[1], public sector	Project funding
Research and investigations for site selection: Site identification, feasibility studies, preliminary planning	Project executor, landowner if necessary, public authorities	Project funding
If necessary, acquisition of land/ acquisition of drainage rights, permissions	Project executor	Project funding, e.g. through EU agricultural and structural funding, federal and state funding programmes, carbon certificates, donation funds from foundations, compensation measures
Planning of measures and approval planning, incl. nature conservation assessments	Project executor	
Planning permissions	Project executor	
Site preparation: Construction implementation	Project executor	
Water management: Installation	Project executor	
Vegetation establishment: sowing or planting if necessary	Agricultural business, project executor	Project funding, e.g. through EU agricultural and structural funding, federal and state funding programmes, development and innovation funding programmes
Success control, Monitoring	Project executor, landowner if necessary, public authorities	

The “Joint Task for the Improvement of Agricultural Structures and Coastal Protection” (GAK) is a central funding instrument for agriculture and forestry, coastal protection and rural areas . The focus is on agricultural structure and infrastructure measures, which can include non-productive, investment-based nature conservation and water management measures[41]. The funds are spent by the federal states via the agricultural investment support programme, among others. The “Landwirtschaftliche Rentenbank”, the german development agency for agribusiness, which provides refinancing for agriculture and rural areas, promotes and finances investments along the entire value chain with programme loans and investment support in adapted machinery for wet land use on organic soils (see above).

In Brandenburg, the climate peatland protection funding programme “Klima-Moorschutz investiv” uses state funds. The programme started in 2024 and will run until 2027[42]. Among other things, it promotes construction measures like water damming (weirs), the acquisition of adapted management technology, the utilisation of biomass from wet peatlands, as well as the development of marketing chains for new products and appropriate advice for farmers.

In addition to investors, private financing options in the area of peatland protection also include donations, sponsoring and the sale of carbon certificates, for example. They mainly focus on rewarding climate protection efforts in the case of water level increases, but could also support wetland use and the utilisation of vegetation.

With non-tradable carbon certificates, such as MoorFutures, buyers can offset their unavoidable emissions (Joosten et al. 2013). MoorFutures certificates are produced in Brandenburg, Mecklenburg-Western Pomerania, Lower Saxony and Schleswig-Holstein. The money from the sale of MoorFutures is used to refinance rewetting measures. MoorFutures can be generated on private or public land. Further (wet) use of the land is not explicitly excluded. Other options for financing from private funds include nature conservation certificates (e.g. the online marketplace for ecosystem services “Agora-Natura”) and donations, such as donation-based funds that secure peatland areas and finance structural rewetting measures (e.g. BUND's Moorland® - KlimaSpende, NABU's German Peatland Protection Fund and Climate Fund, the Schleswig-Holstein Peatland Protection Fund of the “Stiftung Naturschutz”).

Eco accounting and compensation measures represent a further financing option for the planning and implementation of rewetting measures, which is often financed from private funds in the context of intervention compensation “Eingriffsregelung” (Wichmann et al. 2022a). In this case, rewetting measures are planned and implemented by project executing agencies and the associated costs are allocated to ecopoints, which can be marketed to project developers with a compensation obligation or financed as a compensation measure by those obliged to compensate.

41 https://www.bmel.de/DE/themen/laendliche-regionen/foerderung-des-laendlichen-raumes/gemeinschaftsaufgabe-agrarstruktur-kuestenschutz/gak.html
42 https://mluk.brandenburg.de/mluk/de/service/foerderung/fachuebergreifend/rl-klima-moorschutz-investiv/#

6.1.2 Financing options for the management of paludicultures

The costs for the (additional) operational expenses of land management at high water levels are annual expenses that are primarily borne by the proceeds from the marketing of raw materials and products from paludiculture (Tab. 3.10 in Chapter 3.2), but can also be supported as annual payments through the rewarding of ecological services (Tab. 6.2).

In addition to cultivation and harvesting, depending on the type of paludiculture, management also includes active water management (see Chapter 2.2), e.g. irrigation and water level regulation via pumps that require a power supply, maintenance and care, but also the maintenance of ditches and dams. These tasks can be carried out by the farms themselves or by service providers or special-purpose associations. Water management may fall within the remit of water and soil associations or maintenance associations, which levy an area-related charge for this.

In addition to the management costs, it is also necessary to purchase appropriate technology for management and cultivation. The higher maintenance costs per operating hour must be taken into account here (see chapter 2.3).

Tab. 6.2: Overview of cost components, cost bearer / sponsor and financing options for the management of wet and rewetted peatlands/paludicultures (adapted from Schäfer 2016 and Wichmann et al. 2022a). The information on cost coverage is not exhaustive; in individual cases and in the future, the financing options listed may also apply to other cost components and further financing options may be added (see Schäfer et al. 2022).

Cost components	Cost bearer / sponsor	Financing options
Water management: Irrigation	Agricultural business, project executor	Agri-environmental and climate protection measures (AECM, 2nd pillar of the CAP), partly eco-accounting
Vegetation Maintenance	Agricultural business	Revenues from biomass, partly contract nature conservation, AECM
Harvest	Agricultural business, project executor	State/federal funding programs for investment support for the purchase of harvesting techniques
Consultation	Agricultural business	AECM, innovation promotion
(Technology & product) Development	Agricultural machinery manufacturers, processing companies, research institutes, project executors	Innovation promotion, research and development programmes
Success control, monitoring	Agricultural business, project executor	2nd pillar CAP

Agricultural subsidies

Under current legislation in Germany, farmers who cultivate rewetted/wet areas receive direct payments under the Common Agricultural Policy (CAP) subject to the following conditions: (i) if the land is classified as permanent grassland, or (ii) if "agricultural products" as defined in Annex I of the Treaty on the Functioning of the Union (TFEU) are produced through the management of areas, or (iii) if an area previously eligible for direct payments loses its previous eligibility for direct payments due to rewetting under an eco-scheme, an EAFRD measure or a national measure for climate protection or biodiversity conservation, and (iv) if, in addition, the requirements for receiving direct payments based on extended conditionality ("GAEC standards") are met. These conditions comprise a set of uncertainties, i.e. according to permanent grassland definition under German Law, typical wet meadow plants like Juncus and Carex spec. must not predominate to be eligible for payments (GAPDZV § 7 (2) 2). Additionally, of the paludiculture products currently focussed on in Germany (cattail, reed, black alder, sedges, rushes, reed canary grass, peat moss, sundew), only reed canary grass is included in Annex I TFEU as an agricultural product. Besides that, several support programmes for paludiculture crops or for site management with raised water levels are implemented in some federal states (see below) and reduction of legal and administrative barriers are under negotiation.

Payments for ecological services

Measures under the 2nd pillar of the CAP and state programmes in individual federal states

In the previous funding period (2014 - 2022), there were already funding opportunities and measures for paludiculture within the 2nd pillar of the CAP (European Agricultural Fund for Rural Development - EAFRD). This compensates for the additional effort involved in managing peatland soils with high water levels and thus rewards the environmental services achieved (Hirschelmann et al. 2020). In the current CAP funding period 2023-2027, AECM and state programmes exist in peatland-rich federal states that address paludiculture and/or peatland protection.

Bavaria: "contractual nature conservation", which can include the climate-friendly management of peatlands, offers another instrument of remuneration. One example of this is the Bavarian "Vertragsnaturschutz" Contractual Nature Conservation Program (VNP) of the Ministry of the Environment, which supports the nature- and climate-friendly management of meadows and pastures on fens (Bayerischer Landtag 2019). As part of the Bavarian climate protection offensive (November 2019), a "peatland farmer programme" (Moorbauernprogramm) was announced, under which the Bavarian State Ministry of Food, Agriculture and Forestry supports the promotion of "peatland-compatible forms of management" on 20,000 ha by 2029[43]. For the conversion of fens used as cropland into grassland, 3.300 €/ha are payed annually for 5 years; for management of wet grassland 600 – 900 €/ha and for crop paludiculture 2.200 €/ha for 12 years[44].

Brandenburg continues peatland protection payments within the CAP second pillar with a set of measures and funding levels with the AECM „climate protection and water quality", including payments of 350 €/ha annually for 5 years for crop paludiculture on cropland.[45] This adds to the funding programme „Klima-Moorschutz investiv" for in-

43 https://www.stmuv.bayern.de/themen/klimaschutz/klimaschutzgesetz/
44 https://www.stmelf.bayern.de/foerderung/foerderung-von-agrarumweltmassnahmen-in-bayern/index.html
45 https://mluk.brandenburg.de/mluk/de/service/foerderung/landwirtschaft/foerderung-aukm-klimaschutz-und-der-wasserqualitaet/

vestments in harvest machinery for wet soils (see above).

Mecklenburg-West Pomerania established a similar AECM „peat conserving water retention by fixed weir and paludiculture“ (Moorschonende Stauhaltung und Paludikultur), with annually 150 / 450 / plus 450 €/ha (-30 cm / -10 cm water level below surface / cropping paludiculture Phragmites australis or Typha spec.).[46] Also, funding of peatland protection measures through payments for GHG reduction via ERDF will be established (Wichmann et al. 2022b).

Lower Saxony programmed peatland protection AECM, addressing conversion of cropland to grassland on organic soil (2.569 €/ha annually for 7 years) and peat preserving grassland management „moorschonender Einstau“, with annual payments of 536 €/ha (436 €/ha for organic farmer) for 5 years and 20cm below surface ditch water level, which in summer can be lowered to 40 cm.[47]

Schleswig-Holstein established a funding guideline (2024 - 2026) „peatland protection and biological climate protection“ to fund peatland restoration, i.e. investments in water retention and peatland protection measures.[48] Via AECM there are several contractual nature conservation options in place with 5 year obligations for conservation measures on peatlands. I.e. „Weidewirtschaft Moor“ [peatland pastures], without artificial lowering of water level (300 - 400 €/ha annually).[49]

The further development of adapted (harvest) machinery is partly co-funded through research and development programmes, for example as part of national or international joint projects involving research and practice partners[50].

Up-to-date information and advice on Pillar 2 programmes and/or state programmes can be obtained from relevant institutions in the individual federal states, e.g. agricultural advisory services (of farmers' associations), chambers of agriculture and/or the respective responsible authorities.

6.1.3 Utilisation and marketing of biomass from paludicultures

The revenues from the marketing of paludiculture raw materials and products often do not yet cover the costs of investment and management (see Tab. 3.10 and Chapter 2.4). The promotion of investments in new or expanded processing facilities as well as the promotion of (product) developments and their market access is therefore necessary in the short to medium term in order to promote demand for paludiculture raw materials.

The investment-based development of utilisation and marketing can be supported through one-off project funding. In the long term, higher revenues can be generated via product labels or certificates in which a higher end product price is integrated into the climate protection benefits of paludiculture, similar to organic farming (Wichmann et al. 2020, Wichmann et al. 2022a, Rühs & Stein-Bachinger 2018, see also Box 3.1 “Carbon footprint of insulating materials from paludiculture” in Chapter 3.1.3). The basis for the certification of paludiculture products is currently being developed[51].

Innovation funding can support the development and market launch of products from paludicul-

46 https://www.landesrecht-mv.de/bsmv/document/VVMV-VVMV000011575
47 https://www.ml.niedersachsen.de/startseite/themen/landwirtschaft/agrarforderung/agrarumweltmassnahmen_aum/agrarumweltmanahmen-aum-121421.html
48 https://www.stiftungsland.de/fileadmin/pdf/Wer_wir_sind/2024-02-13_Foerderrichtlinie_Moorschutzfonds_und_BIK.pdf
49 https://www.schleswig-holstein.de/DE/landesregierung/themen/umwelt-naturschutz/vertragsnaturschutz
50 i.e. TyphaSubstrat: https://moorwissen.de/typhasubstrat.html and GesaSpAn: https://www.fnr.de/index.php?id=11150&fkz=2220MT002X, see alsoChapter 2.3
51 https://biooekonomie.uni-greifswald.de/project/bueffelwirtschaft/

Tab. 6.3: Overview of cost components, cost bearer/sponsor and financing options for the utilisation and marketing of paludiculture raw materials and products (modified after Wichmann et al. 2022a).

Cost components	Cost bearer / sponsor	Financing options
Construction of new processing plants	(Mergers of) agricultural enterprises, processing companies	Investment and innovation promotion
Development of new products	Companies, (applied) research institutions	Promotion of innovation
Market approval test, etc., establishment of market access	Companies, (applied) research institutions	
Marketing of products	Companies, end users	e.g. product label

ture. Programmes such as the BMWK's Central Innovation Programme for SMEs (ZIM) and the BMBF's "KMU-innovativ programme" are suitable for this purpose, but their funding topics must be specifically expanded to include paludiculture issues and developments (Wichmann et al. 2022a). Currently, innovations are primarily funded via research and development projects, e.g. by the Agency for Renewable Resources via specific funding calls[52] and other European, federal and state-funded project funding (see Chapter 6.1.1).

6.1.4 Outlook

The EU's Carbon Farming Initiative aims to support climate-friendly land management. Pilot projects are currently being implemented via project funding, among other things, to gather experience for scaling up. For example, a certification system is to be developed to reward climate-friendly land use[53].

As early as 2019, Isermeyer et al. made proposals on how CO_2 emissions in agriculture could be priced or how the reduction of emissions could be rewarded. One possibility is to include peatlands in a national emissions trading scheme, whereby emission rights are allocated to landowners who can sell them after the water level has been raised. This would provide long-term financing and planning security for farms with paludicultures.

For the transformation of the German primary industry with its long investment cycles, Agora Industrie et al. (2021) propose climate protection contracts as a short-term instrument with the aim of state-financing the additional costs of switching to climate-friendly production compared to the reference technology. This instrument can be used to initiate the development of green lead markets. Similarly, such an instrument could possibly be used to support agricultural businesses or business associations in switching to paludiculture.

Under the Dutch model, since 2016, only regional associations of agricultural businesses, known as "collectives", have been able to apply for agricultural environmental and climate protection meas-

52 https://pflanzen.fnr.de/paludikultur
53 https://climate.ec.europa.eu/eu-action/carbon-removals-and-carbon-farming_en
54 https://www.dvs-gap-netzwerk.de/agrar-umwelt/naturschutzkooperationen/modell-niederlande/

ures under Pillar 2 of the CAP in the Netherlands[54]. This regional approach is intended to reduce the administrative burden, improve the effectiveness of the measures in terms of biodiversity and give individual farmers more flexibility in implementation. Cooperative approaches are particularly necessary in peatland protection in order to reduce spatial and land use conflicts when converting to paludiculture and to avoid long delays (DVL & GMC 2022).

Technologies and concepts for the capture and storage of CO_2 using biomass (bio-based negative emission technologies - NETs) are a central element of net-zero policy strategies. Paludiculture can lead to negative emissions in long-life products, building materials, CO_2 capture for energy recovery (BECCS), replacement of fossil raw materials and long-term C storage and accumulation in peat. The use of raw materials from paludiculture can thus represent an insetting opportunity for companies to reduce their CO_2 emissions.

6.2 Consulting

Agricultural advisory services on the subject of paludiculture or climate protection on peat soils are scarce. At present, scientific institutions and project executors in the field of peatland (soil) protection, as well as actors from landscape conservation, are the main sources of knowledge and experience for the implementation of rewetting and paludiculture. In addition to the guidelines mentioned above (Chapter 2), information can be found on websites, reports and documentation, for example (mostly in German):

- Landesanstalt für Umwelt Baden-Württemberg, https://www.lubw.baden-wuerttemberg.de/natur-und-landschaft/moorschutz
- Bayerische Landesanstalt für Landwirtschaft (LfL): peatland friendly management options, https://www.lfl.bayern.de/iab/kulturlandschaft/262620/index.php
- Peatland Science Center at HWST, with several paludiculture research projects, https://www.hswt.de/en/research/research-profile/research-institutions/institute-of-ecology-and-landscape/peatland-science-centre
- Bayerisches Landesamt für Umwelt (Bavarian state office for the environment)
- ARGE Klimamoor und Landesamt für Umwelt Brandenburg (Working Community climate peatland and state office for environment Brandenburg), https://www.klimamoor-brandenburg.de/en/home-klimamoor-brandenburg/
- Greifswald Mire Centre (Mecklenburg-Vorpommern): Research- and implementation projects on paludiculture, https://www.moorwissen.de/projects-best-practice.html
- Reed cutter association, i.e. Rohrdachdecker-Innung Mecklenburg-Vorpommern
- Kompetenzstelle Paludikultur im Kompetenz zentrum 3N, Niedersachsen, https://www.paludikultur-niedersachsen.de/ (Competence facility Paludiculture at 3N Competence Center, Lower Saxony)
- Niedersächsischer Landesbetrieb für Wasser wirtschaft, Küsten- und Naturschutz (NLWKN (Lower Saxony State Agency for Water Management, Coastal Defence and Nature Conservation))
- Stiftung Naturschutz Schleswig-Holstein, Ausgleichsagentur Schleswig-Holstein (Nature Conservation Foundation Schleswig-Holstein, Compensation Agency Schleswig-Holstein)
- Landscape management associations: umbrella association Deutscher Verband für Landschaftspflege (DVL), https://www.dvl.org/themen/klimaschutz, local associations (i.e. Landschaftsförderverein Oberes Rhinluch e.V., Lokale Aktion Bündnis Naturschutz in Dithmarschen e.V., ARGE Donaumoos). As inter-

mediaries, the associations can help to find the right contacts, establish cooperation for the use of technology and support the implementation of projects,

- Pilot and Demonstrationprojects on paludiculture, i.e. https://www.z-u-g.org/foerderung/pilotvorhaben-moorbodenschutz/projekte/ and https://www.fnr.de/presse/pressemitteilungen/aktuelle-mitteilungen/aktuelle-nachricht/nasse-moornutzung-auf-dem-weg-zum-markt
- Peatland climate farmer (see also chapter 1.3.4), www.moorklimawirt.de
- Other players from the landscape management sector (e.g. providers and experts in the field of harvesting and transportation technology or logistics)
- Water boards, maintenance associations

For a future exchange and as an advisory contact point for farmers, a peatland farmers' association and a peatland climate farmers' network could be formed. It is also to be expected that, as demand or need increases, the existing agricultural advisory structures will build up and expand their capacities for advising on paludiculture, water retention and management, wet farming and, if necessary, new utilisation paths. Only with a broad transfer of knowledge and practice and a (regional) exchange of experience and growing knowledge, existing knowledge gaps can be filled and obstacles overcome.

More information on consulting

- Schäfer et al. (2022): Anreize für Paludikultur zur Umsetzung der Klimaschutzziele 2030 und 2050 (Incentives for paludiculture to implement climate targets 2030 and 2050),
- Hirschelmann et al. (2020): Moorschutz in der Gemeinsamen Agrarpolitik – Instrumente für eine klimaverträgliche Moornutzung in Deutschland. (Peatland protection within the CAP - instruments for climate friendly peatland use in Germany)
- Contact points in the federal states for applying for AECM, agricultural advisory institutions, farmers' associations
- Websites of funding institutions, e.g. Agency for Renewable Resources e.V., Landwirtschaftliche Rentenbank (Germany's development agency for agribusiness), ZUG gGmbH, state development institutes and state development banks
- Certificates: www.moorfutures.de, www.agora-natura.de
- Foundations, i.e. Deutsche Bundesstiftung Umwelt, NABU-Stiftung Nationales Naturerbe
- DVL & GMC (2022): Zusammenarbeit im Moor – so kommt der Klimaschutz voran! (Cooperation in peatlands - how climate protection makes progress)

7. Concrete examples of implementation

7.1 Practical cultivation of cattail (Typha) - "Teichweide" demonstration site near Neukalen

In the Paludi-PRIMA project[55] a demonstration site was created on approx. 10 ha of fen grassland to test and investigate the cultivation of cattail. The cattail area is located in the Teterower Peene river valley. The fen here has a thick peat layer of up to 4 - 5 metres. The former grassland was dominated by reed canary grass, grazed by a herd of suckler cows and mowed for production of winter fodder (Fig. 7.1). The owner made part of the polder available. Since 2019, valuable experience has been gained in planning and approval processes, site preparation, planting and harvest trials (Fig. 7.2).

Fig.7.1: Area before set-up. Photo: Dahms, T. (2018)

Fig. 7.2: Timeline of cattail cultivation: From set-up in 2019 to the first harvest in 2021.

55 https://moorwissen.de/prima.html

Authorisation procedure, establishment of trial area

These authorities were directly involved in the authorisation procedure:

- Regional nature conservation authorities
- Regional water authorities
- Staatliches Amt für Landwirtschaft und Umwelt, Bereich Wasser (State Office for Agriculture and the Environment, Water Division) (StALU)
- Building authorities

The water and soil conservation authorities and the nature park were involved or informed to this effect. The authorisation procedure is shown in Fig. 7.3.

2018	2018	2019	2021
Contact with participants + on-site appointment	Feasibility study Hydrology + Natura 2000 impact study	Nature conservation licence + water law permit	Application + authorisation Installation of solar modules

Fig. 7.3: Steps in the authorisation procedure for setting up the trial area.

Documents submitted (to the Umweltamt Landkreis Mecklenburgische Seenplatte (Mecklenburg Lake District Environmental Agency)):

- Project description
- Compensation to counterbalance impacts
- Application for exemption/exemption from prohibitions in the landscape conservation area
- Feasibility study: Natura 2000 preliminary assessment and hydrological survey [56]
- Specialist species protection report on nesting birds and results of nesting bird mapping
- Application for approval under water law
- Consent of the owner
- Endorsement from the Ministerium für Landwirtschaft und Umwelt Mecklenburg-Vorpommern (Ministry of Agriculture and the Environment of Mecklenburg-Western Pomerania).

Basis for approval from a nature conservation perspective:

The intended cultivation area had no protected status as a flora-fauna habitat, nature reserve or protected biotope. In addition, it was not included in the funding programme for nature conservation-friendly grassland use. There were therefore no reasons to rule out the suitability of the area for paludiculture (see LM M-V 2017a, Chapter 4). As the cattail area is located within the "Mecklenburgische Schweiz und Kummerower See" landscape conservation area and EU bird sanctuary, an exception or exemption from the prohibitions regulated in the protected area ordinance, particularly regarding changes to the landform and water balance, had to be requested from the regional nature conservation authority for the Mecklenburg Lake district. The request for an exception was justified by the fact that no detrimental effects were to be expected due to the small-scale measures, but an improvement in the efficiency of the ecosystem could be assumed instead.

A Natura 2000 preliminary impact assessment was required due to the location of the site in the "Mecklenburgische Schweiz und Kummerower See"European bird sanctuary. A minor impact on bird life was identified as part of land preparation as a result. This focused on construction-related transport and pollutant emissions, visual and acoustic stimuli as well as vibrations that affected a small number of nesting birds. Land preparation therefore did not have any significant negative impact on the protected area and the conservation

56 Feasibility study for establishment of constructed wetlands for 4 areas in Mecklenburg-Western Pomerania - report on the results for the "Teichweide" area, biota - Institut für ökologische Forschung und Planung GmbH.

objectives were met. The project was therefore permitted in accordance with Section 34 BNatSchG. The expert report on nesting birds under species protection law showed that the requirements for granting an exception in accordance with Section 45 (7) BNatSchG were met, meaning that no countermeasures were necessary to safeguard the conservation status of the species. The nature conservation licence contained specific conditions for the period before and during construction work in order to avoid harming nesting birds.

Basis for approval from a water law perspective:

A permit had to be obtained from the Mecklenburg Lake District State Office for Agriculture and the Environment for the abstraction of surface water from the nearby watercourse in order to create an irrigation system during the vegetation period. An application was submitted for permission under water law to abstract a maximum of 80,000 m³ per year from Teterower Peene. According to the hydrological report, the planned abstraction volume was approx. 0.2 % of the flow rate of the Teterower Peene. The stated purpose was the abstraction of water for irrigation of an agricultural area, which is free of charge according to § 16 (2) 5 LWaG. A temporary permit was issued, which includes conditions such as the recording of actual water abstraction via a water meter. The original idea of watering along the natural gradient from a nutrient-laden tributary of the Teterower Peene (Vurzbach) had to be rejected in advance due to concerns linked to the Water Framework Directive.

Basis for approval from a building law perspective:

No planning permission was required for the construction work to create the cattail area. However, installation of solar modules for a solar-based irrigation system required a building application to the building authority, as solar systems that are independent of buildings are only exempt from planning permission up to a height of 3 metres and a total length of 9 metres, and the total length was exceeded (Mecklenburg-Western Pomerania state building regulations Section 61 LBauO M-V).

Structural implementation: Land preparation & establishment

Various structural measures were carried out to create the cattail area (Fig. 7.4). The construction period was 7.5 weeks and gross costs came to EUR 15,000 per ha:

1. **Soil removal**
   Height differences on a section of the area in question were levelled using a bulldozer. The material could be used to backfill the trench and build the embankment.

2. **Building the embankment (Fig. 7.5)**
   An embankment with a height of around 1.25 metres was built to keep the water in the area. Via several access roads with a flattened bank and a crown width of 3 metres, this can be driven on with the appropriate mashinery and be used for turning and biomass removal.

3. **Construction of ditches**
   External ditches were created to collect drainage water so that the surrounding area, which continues to be used as drained grassland, is not affected by the increased water level in the cattail area. A shallow ditch was also dug within the area to distribute the pumped-in water more effectively. An old drainage ditch that divided the area was filled in. This makes it possible to drive on the site throughout.

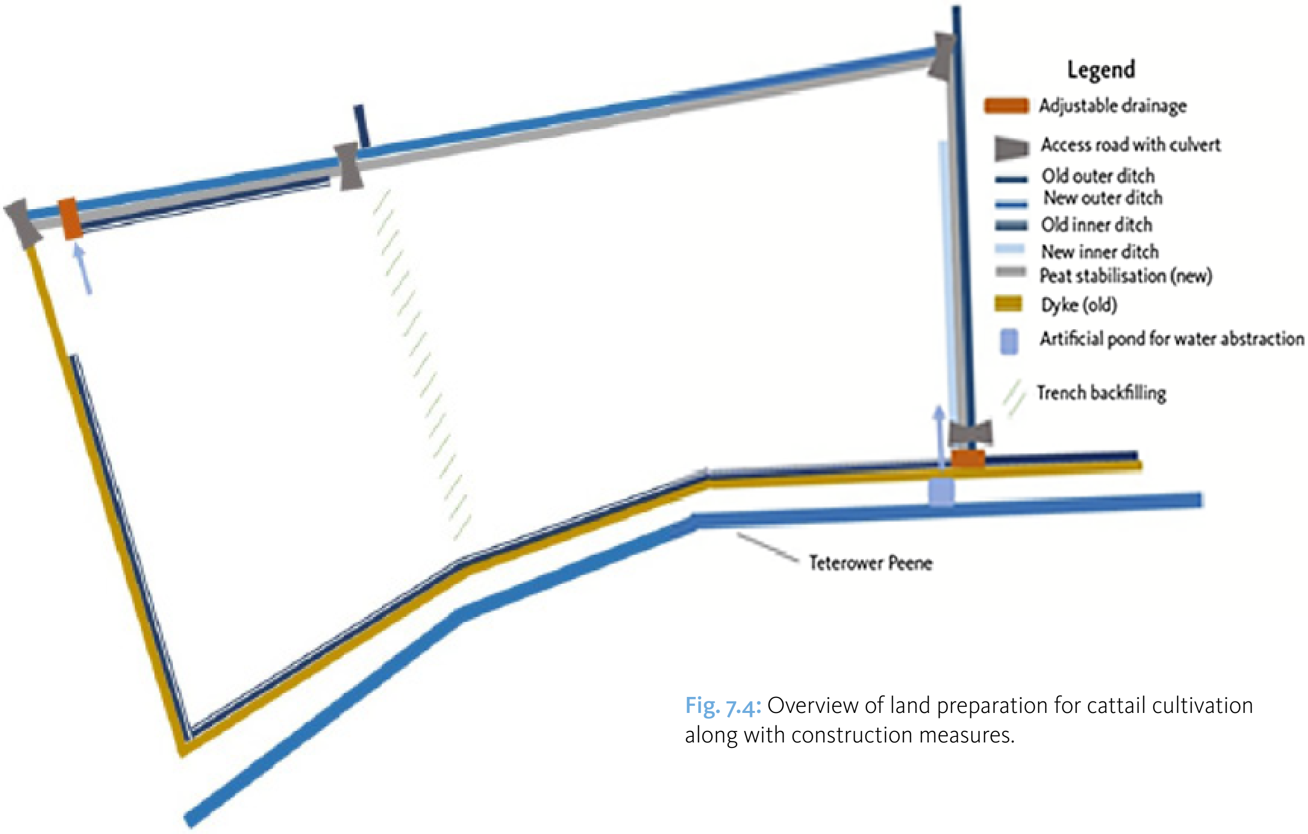


Fig. 7.4: Overview of land preparation for cattail cultivation along with construction measures.

4. **Drainage pipes**
   Drainage pipes were excavated and pipes were cut and backfilled to prevent uncontrolled water run-off.

5. **Irrigation infrastructure**
   A small artificial pond was created on the nearby watercourse for water abstraction. A footbridge was built there to support and secure the submersible pumps. At this point, an inlet with a pressure pipe was laid through the dyke (Fig. 7.6). Two adjustable overflows (monks) were used in order to be able to variably adjust target water levels.

Fig. 7.5: Construction of the embankment. Photo: Dahms, T. (2019)

Fig.7.6: Pressure pipe and spillway. Photo: Neubert, J. (2020)

Planting (2019) and sowing (2020)

Planting material: A nursery specialising in aquatic plants grew 50,000 cattail seedlings (*Typha latifolia* & *Typha angustifolia*) and delivered them in multi-pot pallets (Fig. 7.7).

Mechanical planting: Planting was carried out with two forestry planting machines with 2 m row spacings and with planting distances within the row of 0.5 and 1 m (Fig. 7.8). The water level was raised by pumping in water immediately afterwards. A water level close to the river was set with as little overflow as possible.

Development of the plant population and re-seeding: Late planting at the end of the vegetation period and bird damage led to comparatively poor establishment of the planted seedlings in the first half of 2020. Only about one third of the crop had developed well, showing partial sprouting and cob development. Closing the gaps in the stand was therefore supported by manual and drone sowing (Fig. 7.9).

Pelleted seed could be distributed with pinpoint accuracy at an altitude of 4 - 5 metres with the aid of a metering unit. At the same time, germination of cattails from the seed bank was observed, which was stimulated by fluctuating water levels with overflow and drought. There are larger areas with mixed stands, such as with reed canary grass. Development of the plant population is shown in Fig. 7.12 to 7.15.

During the vegetation period (April - September), irrigation was necessary depending on the weather. A decentralised solution had to be found as there is no connection to the power grid. A needs-based irrigation system was installed in summer 2021 after difficulties with adjusting the water level in 2020 due to a lack of available technology. A solar-based basic supply is supplemented by a diesel-powered emergency generator for higher water requirements. For the first mechanical harvest, work began two months in advance to lower the water level to the soil surface. This aimed to increase the trafficability of the area.

Fig. 7.7: Unloading the planting material.
Photo: Neubert, J. (2019)

Fig. 7.9: Drone with metering unit for sowing.
Photo: Dahms, T. (2020)

Fig. 7.8: Planting with a planter. Photo: Dahms, T. (2019)

First harvest (2021)

A first mechanical trial harvest was carried out over approx. 1.5 ha in December 2021. The biomass was harvested separately in two areas with a Typha-dominant stand and a mixed Typha-reed canary grass stand. Specialised technology used: Track-based Softrak 120 (Loglogic) with front-mounted chopper (ELHO double chopper) and mounted 11 m³ bunker (Fig. 7.10).

The biomass was loaded with a forestry crane onto a transfer site at the edge of the area on mineral substrate and transported away for drying using conventional agricultural machinery (Fig. 7.11).

Fig. 7.10: First cattail harvest as chopped biomass.
Photo: Wichmann, S. (2021)

Fig. 7.11: Loading of chopped cattail biomass.
Photo: Dahms, T. (2021)

Series of images showing area development of cattail cultivation between 2019 - 2021 (all photos: Dahms, T.):

Fig.7.12: Cattail area planted and wetted in October 2019.

Fig.7.14: End of first vegetation period of cattail area in November 2020.

Fig.7.13: Start of first vegetation period of cattail area in May 2020.

Fig.7.15: First cattail area harvest in December 2021.

7.2 Practical cultivation of peat moss (Sphagnum) - "Hankhauser Moor" demonstration site near Rastede, Ammerland district (Lower Saxony)

Inspired by a method developed in Canada where peat moss vegetation is transferred for restoration of peat extraction sites (so-called 'moss layer transfer technique'¸ Quinty & Rochefort 2003), the first pilot site for peat moss paludiculture was established in 2004 on approx. 1,200 m² in Esterweger Dose (Cloppenburg district, Lower Saxony) and scientifically monitored over 10 years (Gaudig et al. 2017). Bog grassland areas, which cover approx. 90,000 ha in Lower Saxony, have a far greater area potential for peat moss paludiculture than peat extraction areas (~ 500 ha) in Germany (Wichmann et al. 2017). Following the first successful pilot trial on a peat extraction area in 2011, a further demonstration area was therefore set up on an area that had previously been used intensively as bog grassland. It is located on the Hankhauser Moor, which covers around 900 hectares and is part of the Delfshausen-Ipwegermoor complex. This covers a total area of approx. 4,500 ha, is located on the edge of the geest and consists of several merging bogs, primarily used for agricultural purposes (mainly as grassland). To the east, there are further extensive areas of bog used for agriculture in the district of Wesermarsch. The peat thickness in the Hankhauser Moor is approx. 1.5 - 2 m, a white peat layer (slightly decomposed peat moss) is still largely present. Parts of the peatland are already below sea level after decades of drainage. A receiving water body drains the water into the Jade and the Jade Bight.

As a preliminary study for the application for a peat extraction licence, an integrated area development concept was drawn up (Hofer & Pautz 2005) to provide comprehensive analysis of the area. The owner (Deutsche Torfgesellschaft mbH, DTG) initially made an area of approx. 4 ha available, which was converted from bog grassland to peat moss paludiculture in 2011. This area was expanded by 10 ha in 2016 and by a further 3 ha in 2020, making a total area of 17 ha. The demonstration area has been and continues to receive extensive and varied scientific support in three projects (MOOSGRÜN, MOOSWEIT, OptiMOOS). Torfwerk Moorkultur Ramsloh GmbH & Co KG is involved. as the most important practical partner as a shareholder of DTG and therefore co-owner of the land as well as being a land manager.

The following section provides detailed information on the authorisation procedure, the feasibility study and land preparation.

Authorisation procedure for practical peat moss paludiculture on Hankhauser Moor, Ammerland district (Lower Saxony)

Authorities involved

1. Amt für Umwelt und Wasserwirtschaft LK Ammerland (Office for Environment and Water Management, Ammerland District)
2. Amt für Bauwesen und Kreisentwicklung (Office for Construction and Regional Development)

Steps in the authorisation procedure for establishment

0. Contacting stakeholders & on-site appointments with authorities
1. Authorisations: approvals in line with nature conservation and water law, building permit

Available documents

- Integrated area development concept on “Hankhauser Moor" incl. studies on vegetation, fauna, hydrology, peat thicknesses, peat stratigraphy

Documents submitted (by landowner)

- Application for permission under water law
- Application for a nature conservation licence
- Building application

Basis for authorisation from a nature conservation perspective

- No protection status as a flora-fauna habitat, nature reserve, landscape conservation area, protected animal and plant species or similar available, no classification in funding programmes for nature conservation-friendly grassland use
- Landscape structure remains intact, dam height must not exceed 1 metre

Basis for authorisation from a water law perspective

- Application for permission under water law to abstract surface water from the Schanze (receiving water body), max. 25,000 m³ each year (for 6.6 ha net production area)
- Actual water abstraction is recorded
- No negative impact on adjacent sites and water system
- According to §8 in conjunction with §§ 9 and 10 WHG, water abstraction constitutes utilisation of water bodies, cost decision according to Nds. Verwaltungskostengesetz (Lower Saxony Administrative Costs Act) and the general schedule of fees.

Preliminary study for practical peat moss paludiculture on Hankhauser Moor, Ammerland district (Lower Saxony)

According to the Integriertem Gebiets- und Entwicklungskonzept Hankhauser Moor – Hydrologie/Folgelandschaft (Integrated Area and Development Concept on Hankhauser Moor - hydrology/subsequent landscapes (Hofer & Pautz 2005)), the trial area was categorised as mesophilic grassland of moderately damp sites, mown pasture. The following data was collected by the University of Greifswald and its partners as part of the research projects as preparation for establishment of the demonstration area:

- Creation of a terrain model by measuring using differential GPS,
- Peat stratigraphy, vegetation,
- Investigation of the chemical and physical characteristics of peat,
- Recording the hydrological conditions (literature research, preparation of an initial site water balance) to determine the distance between the irrigation ditches as well as the water requirements.

Area set up for practical peat moss paludiculture on Hankhauser Moor, Ammerland district (Lower Saxony)

Photos: G. Gaudig

Land preparation

Topsoil removal and creation of a flat surface

- Decision on the production system (with or without embankments)
- Staking out (size) and levelling (depth) future peat moss production areas
- Transporting the excavator to the site
- Use the excavator (approx. 30 - 50 cm, laser-controlled) for removal of the sod or the mineralised, limed and nutrient-rich topsoil in order to obtain a flat surface on the peat moss production areas and thus ensure a permanently good water supply for the peat mosses

Installation of infrastructure for automatic water management

- Digging small ditches (approx. 50 cm wide, 50 cm deep)
- Installation of overflows for excess water
- Installation of pumps and underground connection pipes for irrigation
- Installation of underground cables, sensors and set-up of a container as a switching and control centre

Construction of embankments as infrastructure for management and harvesting of peat moss production areas

- Shaping the embankments by using the material gained from topsoil removal

Distribution of peat moss

Procurement and storage of seeds

- Procurement of peat moss ›› Seeds
- Procurement of straw ›› Cover

Distribution of peat moss fragments and straw

- Transport of machines, peat moss and straw to the area
- Loading a manure spreader mounted on a snow groomer with a grab dredger
- Spreading the peat moss and manual post-processing for more even spreading with a leaf rake
- Spreading straw to cover the peat mosses

  ›› Establishment of peat moss production areas

Rewetting

- Initial filling of the irrigation ditches
- Adjustment of overflows, installation of non-return flaps

  ›› Immediate raising of the water level to minimise the drying out of peat mosses

Land management and harvesting at on-site peat moss paludiculture on Hankhauser Moor, Ammerland district (Lower Saxony)

Maintenance mowing

- Conversion of an excavator with 15 m long arm and approx. 4 m wide mowing bucket
- Mowing the peat moss production areas with a converted excavator from the embankment: Cutting of vascular plants above the peat moss surface, depositing the mown material on the embankment; frequency: approx. every 6 - 8 weeks during the vegetation period
- Mulching the embankments with a tractor and attached mulcher, leaving the mulch material on the embankment; approx. 6 times a year

Water management

- Setting the water levels: Increasing with the growth of peat mosses; control of the automatic irrigation system
- Maintenance of the ditches from the embankment using an excavator and mowing bucket, material excavated from the ditch is deposited on the embankment; once a year; central ditches can become partially overgrown with peat moss if the peat moss lawn can be irrigated
- Maintenance of pumps and the measuring system (e.g. repairs after a lightning strike)
- Flushing the connecting pipes between peat moss production areas
- If applicable, protection from muskrats/nutrias

Infrastructure maintenance

- Maintenance of the access road incl. bridges
- Maintenance of the container as a central control centre and repair of its substructure

Harvest

- Conversion of an excavator with 15 m long arm and approx. 2 m wide mowing basket
- Harvesting the peat moss production areas from the embankment with a converted excavator: Cut peat moss to a depth of approx. 5 - 7 cm (first harvest 5 years after establishment, Fig. 7.16)
- Removal of harvested peat moss biomass with a dumper truck
- Harvest frequency depends on the regeneration capacity of the cut peat moss lawn

Fig. 7.16: First mechanical harvesting of peat mosses with mowing bucket in summer 2016. Photos: Schroeder, P.

Further literature about the peat moss paludiculture area on Hankhauser Moor

For information on set-up costs, see the Crop paludiculture with peat moss section in Chapter 2.4

For information regarding the use and markets for peat moss biomass, see Chapter 3.1.6

Brust, K., Krebs, M., Wahren, A., Gaudig, G. & Joosten, H. (2018): The water balance of a Sphagnum farming site in north-west Germany. Mires and Peat, 20(10).

Gaudig, G. & Krebs, M. (2016): Torfmooskulturen als Ersatzlebensraum – Nachhaltige Moornutzung trägt zum Artenschutz bei. (Peat moss cultures as a substitute habitat - Sustainable peatland utilisation contributes to species protection). Biologie in unserer Zeit (biology in our time), 46 (4), 251–257.

Gaudig, G., Krebs, M. & Joosten, H. (2020): Sphagnum growth under N-saturation: interactive effects of water level and P or K fertilization. Plant Biology, 22(3).

Gaudig, G., Krebs, M., Prager, A., Wichmann, S. et al. (2018): Sphagnum farming from species selection to the production of growing media: a review. Mires and Peat, 20(13).

Günther, A., Jurasinski, G., Albrecht, K., Gaudig, G., Krebs, M. & Glatzel, S. (2017): Greenhouse gas balance of an establishing Sphagnum culture on a former bog grassland in Germany. Mires and Peat, 20(2).

Muster, C., Gaudig, G., Krebs, M. & Joosten, H. (2015): Sphagnum farming: the promised land for peat bog species? Biodiversity and Conservation, 24.

Temmink, R.J.M., Fritz, C., van Dijk, G., Hensgens, G., Lamers, L.P.M., Krebs, M., Gaudig, G. & Joosten, H. (2017): Sphagnum farming in a eutrophic world: The importance of optimal nutrient stoichiometry. Ecological Engineering, 98.

Vroom, R., Temmink, R.J.M., van Dijk, G., Joosten, H., Lamers, L.P.M., Smolders, A.J.P., Krebs, M., Gaudig, G. & Fritz, C. (2020): Nutrient dynamics of Sphagnum farming on rewetted peat grassland in NW Germany. Science of the Total Environment, 726, 138470.

Wichmann, S., Krebs, M., Kumar, S. & Gaudig, G. (2020): Paludiculture on former bog grassland: Profitability of Sphagnum farming in North West Germany. Mires and Peat, 26(08).

Wichmann, S., Prager, A. & Gaudig, G. (2017): Establishing Sphagnum cultures on bog grassland, cut-over bogs, and floating mats: procedures, costs and area potential in Germany. Mires and Peat, 20(3).

7.3 Implementation of rewetting with extensive grazing on moist to wet sites in the Swabian Donaumoos (Gundelfinger Moos nature reserve)

The Swabian Donaumoos in the district of Günzburg on the border between Bavaria and Baden-Württemberg covers a core area of 5,000 hectares, including the Leipheimer and Gundelfingen Moos nature reserves. The Arbeitsgemeinschaft Schwäbisches Donaumoos e.V. (ARGE Donaumoos) working group was founded in 1990 as a landscape conservation association aiming to promote the "conservation and development of an open, ecologically intact reed and river landscape with nature conservation-compatible land use" in the Swabian Donaumoos. Following rewetting of the Leipheimer Moos in the nature reserve, there are now plans to rewet the 600-hectare Gundelfinger Moos on largely agricultural land. Agricultural use is to be maintained whilst closely collaborating with the agricultural sector, particularly in the peripheral areas. ARGE Donaumoos would like to promote extensive grazing and crop paludiculture in particular here. Depending on the water level after rewetting, peat conservation or continued low peat depletion can be achieved including a considerable reduction in GHG emissions. It can be assumed that some of the extensively used areas will continue to be slightly peat-depleting. As paludiculture only covers peat-preserving cultivation, the term cannot be used everywhere. The project is presented here anyway, as utilisation of wet meadows on the edges of paludiculture areas or on areas that are not completely waterlogged is an option that can lead to significant reductions in GHG emissions and also create synergies with nature conservation. Furthermore, the valuable experience of rewetting a large contiguous area, the joint design with the land users as well as finding solutions with the owners will be presented.

Planning, authorisation and implementation of rewetting

The aim of the entire project is to restore a water balance in the Gundelfinger Moos that is typical of peatlands, with subsequent natural vegetation development along with realisation of crop paludiculture outside the protected areas in future. This area-orientated approach aims to restore the water balance with efficient and cost-effective measures. The aim is to achieve a ground water level of < 20 cm below surface all year round. However, due to subsidence and remodelling, the peatland area has changed to such an extent that it can only be partially rewetted up to soil surface of the terrain via these means. Otherwise, larger areas would be permanently overflown. Removal of the drainage system as well as the existing water supply in summer are also unlikely to be sufficient to achieve high water levels all year round. Various irrigation options were examined to cover the deficit and the focus is currently on two successive measures. An application from the Swabian government for rewetting of the Gundelfinger Moos was submitted to the Dillingen District Office in autumn 2020 for measures 1 and 2 (as of July 2022: in progress). The water rights application is subdivided into:

- Measure 1: Expansion of surface waters (**planning approval**): Removal of ditches by backfilling or partial backfilling (Fig. 7.17)
- Measure 2: Water utilisation (**qualified permission**): Discharge of surface water from the northern ditches into the Gundelfinger Moos nature reserve

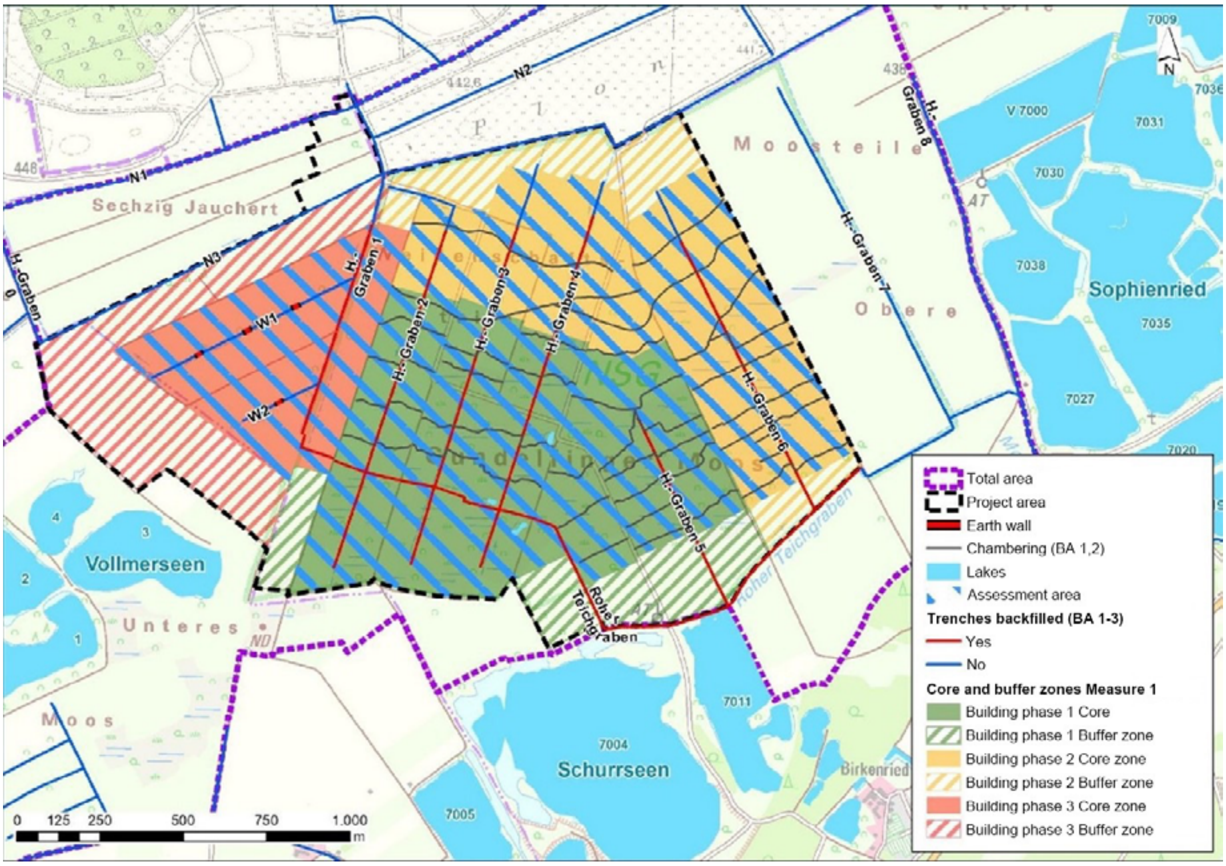


Fig. 7.17: Overview of measure 1: Removal of drainage in Gundelfinger Moos (backfilling of the ditches up to 30 cm above ground level of the terrain; creation of a chamber). Source: ARGE Donaumoos; created by Anders & Raum.

Land reorganisation, framework agreement

Once water law approvals have been obtained, a **land reorganisation procedure** shall be initiated to bring about a reallocation of use and transfer the core zone to public ownership (preferably 100%). The area is currently in the possession of over 300 owners.

Compensation issues are governed by a **"framework agreement"**[57] that has already been finalised between the water rights holder (Government of Swabia awards a contract to ARGE Donaumoos to supervise the project) and the farmers' associations. This framework agreement regulates the modalities of damage compensation in the event of project-related moisture damage on private land. The main points are:

- The burden of proof lies with the project executor.
- The core zone (Fig. 7.18) should be 100 % publicly owned wherever possible. Extensive usage remains possible. No compensation is provided in normal cases, i.e. when public areas are waterlogged. On private areas: Compensation payments such as in the buffer zone.
- The buffer zone (Fig. 7.18), will continue to be private property and therefore be potentially affected. The owners have agreed to the waterlogging. Adaptation of use in accordance participation remains voluntary. If waterlog-

57 https://www.arge-donaumoos.de/fileadmin/Media/user_upload/EndfassungRahmenvereinbarungmitUnterschriften.pdf

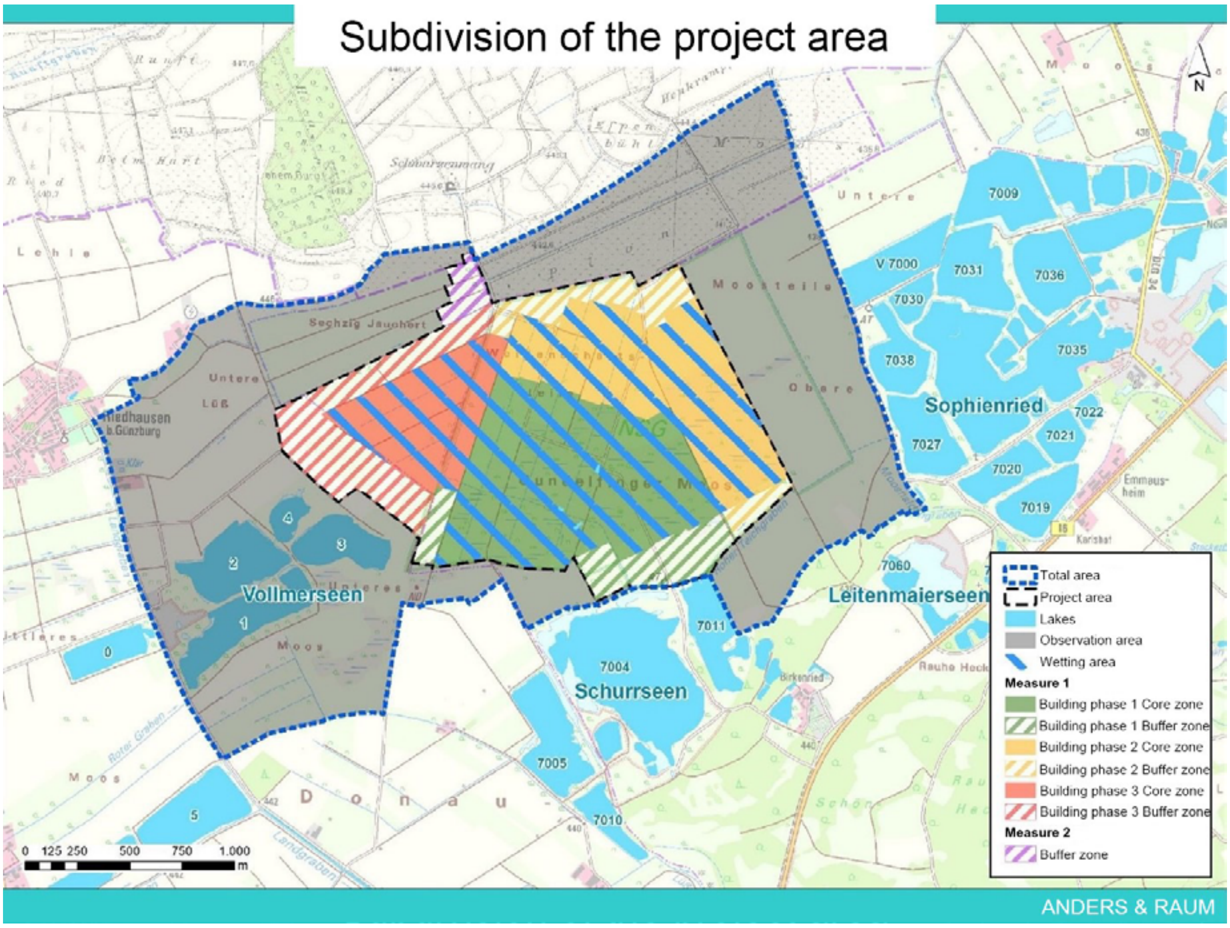


Fig. 7.18: Overview of the entire project with observation area, core zone and buffer zone. Source: ARGE Donaumoos, created by Anders & Raum.

ging with the moisture level (agricultural target use) is recommended and supported with state funding programmes or other funds, however damage occurs then this can be reported by the farmer. Presence of waterlogging is established by the committee. If damage is detected, one-off waterlogging compensation is granted based on the target land use, based on an assessment table. No further proof provided by the farmer is necessary.

- Within the observation area (Fig. 7.18) the property areas and usage remain as they are. The owners' consent to the measures was not required. Adaptation of use in accordance with the moisture level (agricultural target use) is not explicitly sought, but is welcome and supported by state funding. Compensation for waterlogging is granted upon application and in individual cases in accordance with BBV estimation guidelines, but only for proven project-related waterlogging.

Coordination & communication

The project has been prepared, coordinated and accompanied by extensive public relations work and communications by ARGE Donaumoos for around 15 years. Thanks to many years of work, there is a relationship of trust with everyone involved. Important contributions include:

- Owners' meetings
- Field days
- Thematic round tables on land reorganisation, wetland management
- Information events for owners, land users, municipalities, specialist authorities and nature conservation stakeholders as well as interested citizens
- Public relations: Website, information letters, articles
- Consultations

ARGE Donaumoos initiated the foundation of "Naturweiden Donaumoos e.V.", an association for the exchange of expertise and experience between farmers as well as with interested citizens from nearby areas. For example, there are animal exchanges as well as walks and cycle tours to the grazing animals, during which the grazing of wetlands and its benefits are discussed.

Implementation of rewetting measures is being financed with funds from the KLIP programme in Bavaria and funds from a state treaty between Baden-Württemberg and Bavaria. The far-reaching work carried out by ARGE Donaumoos for coordination, consultation and implementation is supported with funds from various projects as well as funds from the state treaty and the government of Swabia.

Conversion of utilisation to grazing of moist and wet meadows

ARGE Donaumoos is looking for, advising and supporting farmers in establishing grazing areas for peatland areas that are already wet as well as those that will be so in the future. A wide range of information and experiences are shared on the ARGE Donaumoos website[58]. The "LaNu" project[59] supports farmers by financing the organisation and facilities (shelter, feeding stations, fences, etc.). The farmer handles both assembly as well as procurement of the animals. It is up to the farmer to decide which breed to use; Scottish Highland, Dexter and water buffalo are recommended (see notes below), with a stocking density of 0.6 to max. 1 LU per ha (in drier areas). Areas with high water levels all year round can only be grazed by water buffalo all year round. The other animals are better suited to rather moist sites (no paludiculture).

Suitable animals for year-round grazing:

1. Scottish Highland cattle: robust, hardy, frugal; year-round grazing possible without shelter, but is usually encouraged by the vet anyway; no selected feeding behaviour
2. Water buffalo: very calm and relaxed, tolerates very wet areas, eats rushes, cattail, reeds; needs shelter
3. Restricted: Dexter and other light cattle breeds; year-round grazing only possible to a limited extent; shelter required

58 Additional Information: https://www.arge-donaumoos.de/arbeitsfelder/themen/landwirtschaft/beweidungsinfos/
59 LaNu" project = "Landnutzung" (Land use), encouraged by the Swabian government. Aim: extensive use of grasslands. 5-year funding period in each case

Pasture equipment

Fence: Either metal posts or water-resistant wooden posts with plastic insulators are used in the Swabian Donaumoos. Wooden posts generally have a better hold in the ground, but some of them have to be replaced after a certain period of time (10 - 20 years).

Maintenance is more complex than with a conventional pasture, as the grass is very lush and the fence line has to be mown frequently. Sufficiently powerful electric fence energisers make maintenance easier as they are less sensitive to vegetation, as are ammeters that report a voltage drop to a mobile phone.

Water supply: A good water supply for the animals is important, as surface water or water in the ditches may no longer be available during dry weather. In the Swabian Donaumoos, float-controlled 12-volt pumps are used, which are connected to the solar-powered fence batteries and ensure sufficient water supply. The floor should be firm around the drinking trough. Open waterholes are favoured by the animals if available.

Supplementary feeding: usually takes place with local fodder from October to the end of April (Fig. 7.19 on left).

Fig. 7.19: Left: Scottish Highland cattle are fed in winter. Right: Shelter for water buffalo on firm ground for resting. Photos: ARGE Donaumoos

Fig. 7.20: A firm access road with gravel leading to the resting areas, water supply and feeding area. Photo: ARGE Donaumoos

Resting areas & access: Resting areas and sufficient shade must be available to the animals, e.g. with pasture tents or simple shelters made of logs. Gravelled resting areas were also created (Fig. 7.19 on right) after being financed via various projects. The animals are fed, watered and treated there. The path to it may also need to be paved. This ensures access to the animals all year round as well as in all weathers (Fig. 7.20). This also prevents trampling damage to the sensitive peatland soil around feeding and watering points. The resting areas can be completely dismantled.

Shooting: This is recommended by ARGE Donaumoos and carried out in the area. This is only possible if the animals are kept all year round. A bullet shot enables a stress-free death for the animal. Meat quality is far better as a result. For the owner and the animal, there is no need to catch, transport or move the animal to an unfamiliar environment. Veterinary specifications must be observed.

Profitability & financing

It takes several years to set up suckler cow husbandry and farmers do not earn any income from this type of farming until enough animals are ready for slaughter. In contrast, there are also high purchase costs for the animals: A water buffalo costs between EUR 2,500 and 4,000, Scottish Highland cattle and Dexter cattle cost between EUR 1,800 and 2,300. Starting extensive grazing on wet land is therefore only economically viable for farmers at the moment if they receive financial and/or organisational support. Grazing of one hectare would require at least EUR 1,200 per year as a bonus for ecological services. However, farmers can only receive EUR 420 per hectare in Bavaria for extensive grazing via the contractual nature conservation programme (as of 2022).

For this reason, ARGE Donaumoos provides support by providing the "hardware" for pasture equipment as well as with acquisition of land.

Various funding programmes can be used to support the implementation of grazing, including contractual nature conservation programmes (VNP) and cultural landscape programmes (KULAP). ARGE Donaumoos provides support in the form of land acquisition and consultancy.

Marketing can take the form of direct marketing (see also Chapter 3). Many conditions and investments must be made in advance for expansion of an operational branch: such as sufficient land must be available for planned herd growth (grazing area and winter fodder areas), and long-term financial

Fig. 7.21: BioMoos GbR consists of Tina Niess, Georg Wiedenmann and Winfried Bayer. Photo: Peter Roggenthin

support must be secured via support programmes for extensive grazing.

Supported by ARGE Donaumoos, three farms joined forces in 2018 to form Biomoos GbR based on such considerations and merged their land in the Gundelfinger Moos nature reserve in order to preserve the species-rich fen meadows with grazing animals (Fig. 7.21). Together they manage 46 ha of wet meadows, of which 26 ha are grazed all year round with Scottish Highland cattle and 20 ha are mown for winter fodder using adapted grassland technology. Cooperation means forces can be pooled more efficiently whilst minimising risk. More info at: www.moorklimawirt.de

For detailed information on both the planning and implementation status, see also:

- https://www.arge-donaumoos.de/arbeitsfelder/projektgebiete/gundelfinger-moos/
- https://www.arge-donaumoos.de/arbeitsfelder/themen/moor-wiedervernaessung/historie-und-bau-gundelfinger-moos/

Bibliography

Abel, S., Barthelmes, A., Gaudig, G., Joosten, H., Nordt, A. & Peters, J. (2019): Klimaschutz auf Moorböden – Lösungsansätze und Best-Practice-Beispiele. (Climate protection on peatlands - solutions and best practice examples) Greifswald Moor Centrum-Schriftenreihe, 03/2019.

Agora Industrie, FutureCamp, Wuppertal Institut & Ecologic Institut (2021): Klimaschutzverträge für die Industrietransformation: Kurzfristige Schritte auf dem Pfad zur Klimaneutralität der deutschen Grundstoffindustrie. (Climate protection agreements for industrial transformation: short-term steps on the path to climate neutrality in the German primary industry) Agora Industrie, Berlin, 120 S.

Ahmad, S., Liu, H., Günther, A., Couwenberg, J. & Lennartz, B. (2020): Long-term rewetting of degraded peatlands restores hydrological buffer function. Science of The Total Environment, 749.

Amberger-Ochsenbauer, S. & Meinken, E. (2020): Torf und alternative Substratausgangsstoffe. (Peat and alternative substrate constituents) Hrsg. Von Bundesanstalt für Landwirtschaft und Ernährung. Bonn, 52 S.

Atif, M. & Scholz, M. (2011): Nutrient accumulation in Typha latifolia L. and sediment of a representative integrated constructed wetland. Water, Air, & Soil Pollution, 219 (1–4), 329–341.

Audet, J., Zak, D., Bidstrup, J. & Hoffmann C.C. (2020): Nitrogen and phosphorus retention in Danish restored wetlands. Ambio 49, 324–336.

Awasthi, A., Singh, G., Dhyani, V., Kumar, J., Reddy, Y.S., Adarsh, V.P., Puthiyamadam, A., Mullepureddy, K.K., Sukumaran, R.K., Ummalyma, S.B., Sahoo, D. & Bhaskar, T. (2019): Co-pyrolysis of phumdi and para grass biomass from Loktak Lake. Bioresource technology 285.

Babula, P., Adam, V., Havel, L. & Kizek, R. (2009): Noteworthy secondary metabolites naphthoquinones – their occurrence, pharmacological properties and analysis. Current Pharmaceutical Analysis, 5(1), 47–68.

Baranyai, B. & Joosten, H. (2016): Biology, ecology, use, conservation and cultivation of round-leaved sundew (Drosera rotundifolia L.). Mires and Peat, 18, 1 – 28.

Baranyai, B., Krebs, M., Oehmke, C., Joosten, H. (2022): Total biomass and annual yield of Drosera on cultivated Sphagnum in north-west Germany. Mires and Peat, 28, 31, 19pp. doi: 10.19189/MaP.2020.OMB.StA.1995

Barthelmes A., Abel S., Barthelmes K.-D., Couwenberg J., Kaiser M., Reichelt F., Tanneberger F. & Joosten H. (2021): Evaluierung von Moor-Wiedervernässungen in Deutschland – Ergebnisse, Erfahrungen und Empfehlungen. (Evaluation of peatland rewetting in Germany - results, experiences and recommendations) Naturschutz und Biologische Vielfalt, 171, 121-148.

Bayerischer Landtag (2019): Anfragen zum Plenum zur Plenarsitzung am 27. November 2019, Auszug aus Drucksache 18/5058: Frage Nummer 51 mit der dazu eingegangenen Antwort der Staatsregierung. Abgeordneter Christoph Skutella (FDP). (Questions to the plenary for the plenary session on November 27, 2019, excerpt from printed matter 18/5058: Question number 51 with the answer received from the state government. Member of Parliament Christoph Skutella (FDP)) Drucksache 18/3827.

Becker, L., Wichmann, S., Beckmann, V. (2020): Common Reed for Thatching in Northern Germany: Estimating the Market Potential of Reed of Regional Origin. Resources, 9 (12), 146

Birr, F., Abel, S., Kaiser, M., Närmann, F., Oppermann, R., Pfister, S., Tanneberger, F., Zeitz, J. & Luthardt, V. (2021): Zukunftsfähige Land- und Forstwirtschaft auf Niedermooren – Steckbriefe für klimaschonende, biodiversitätsfördernde Bewirtschaftungsverfahren. (Sustainable agriculture and forestry on fens - fact sheets for climate-friendly, biodiversity-promoting management methods) Auszug aus den BfN-Skripten 616, bearb. Fassung. Hochschule für nachhaltige Entwicklung Eberswalde und Greifswald Moor Centrum (Hrsg.). Eberswalde/ Greifswald, 148 S.

BMEL (2022): Torfverwendung reduzieren – Klima schützen. (Reduce peat use - protect the climate) Bundesministerium für Ernährung und Landwirtschaft. Webseite aufgerufen am 13.07.2022: https://www.bmel.de/DE/themen/landwirtschaft/pflanzenbau/ gartenbau/torf.html

BMUV (2022): Aktionsprogramm Natürlicher Klimaschutz. Eckpunktepapier. (Natural Climate Protection Action Program. Key issues paper)

BMWK, BMUV & BMEL (2022): Ausbau der Photovoltaik auf Freiflächen im Einklang mit landwirtschaftlicher Nutzung und Naturschutz. (Expansion of photovoltaics on open spaces in harmony with agricultural use and nature conservation) Bundesregierung, 2 S.

Bozell, J.J. & Petersen, G.R. (2010): Technology development for the production of biobased products from biorefinery carbohydrates — the US Department of Energy's "Top 10" revisited. Green Chem. 12(4), 539.

Brust, K., Krebs, M., Wahren, A., Gaudig, G. & Joosten, H. (2018): The water balance of a Sphagnum farming site in north-west Germany. Mires and Peat, 20(10), 1–12.

Bunzel-Drüke et al. (2019): Naturnahe Beweidung und Natura 2000. Ganzjahresbeweidung im Management von Lebensraumtypen und Arten im europäischen Schutzgebietssystem NATURA 2000. (Near-natural grazing and Natura 2000. Year-round grazing in the management of habitat types and species in the European protected area system NATURA 2000) Heinz Sielmann Stiftung, Duderstadt.

Burgess, S., Leisen, J., Kraftschik, B., Mubarak, C., Kriegel, R. & Koros, W. (2014): Chain Mobility, Thermal, and Mechanical Properties of Poly(ethylene furanoate) Compared to Poly(ethylene terephthalate). Macromolecules 47, 4, 1383–1391

Carius, W. (2020): Feststoffvergärung (Feststofffermentation). (Solid matter fermentation) Vortrag auf der Online Informationsveranstaltung "Verwertungsmöglichkeiten von Biomasse aus nassen Mooren: Klimaschutz, Naturschutz und regionale Wertschöpfung, 10.+11. Dezember 2020.

Carius et al. (2011): Effizienzsteigerung von Grünlandsubstraten in der Biogasgewinnung unter Berücksichtigung naturschutzfachlicher Belange. (Increasing the efficiency of grassland substrates in biogas production while taking nature conservation concerns into account) Grünland. Hrsg. V. BUND Landesverband Niedersachsen e.V. Prinzhöfte.

Cook, C.D.K., Gut, B.J., Rix, E.M. & Schneller J. (1974): Water Plants of the World. Springer Dordrecht.

Cruse, F., Dietz, W., Höller, M. & Szafera, S. (2015): Entwicklung eines Verfahrens zur Gewinnung von Gras als Rohstoff und Verarbeitung für die Herstellung von Papierprodukten unter besonderer Berücksichtigung des Aufbaus einer nachhaltigen Wertschöpfungskette. (Development of a process for the extraction of grass as a raw material and processing for the manufacture of paper products with special consideration of the development of a sustainable value chain) DBU-Bericht, 116 S.

Czubaszek, R., Wysocka-Czubaszek, A., Wichtmann, W. & Banaszuk, P. (2021): Specific Methane Yield of Wetland Biomass in Dry and Wet Fermentation Technologies. Energies, 14, 8373.

Czybulka, D. & Kölsch, L. (2016): Rechtliche Rahmenbedingungen. (Legal framework) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore.

Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 143-149.

Da Silva Veiga, P.A., Schultz, J., da Silva Matos, T.T., Fornari, M.R., Costa, T.G., Meurer, L. & Antonio Mangrich, A.S. (2020): Production of high-performance biochar using a simple and low-cost method: Optimization of pyrolysis parameters and evaluation for water treatment. Journal of Analytical and Applied Pyrolysis, 148.

Dahmen, N., Lewandowski, I., Zibek, S. & Weidtmann, A. (2018): Integrated lignocellulosic value chains in a growing bioeconomy: Status quo and perspectives. GCB Bioenergy 2019, 11, 107–117.

Dahms, T. (2017): Biomass harvest on wet peatlands. Assessment of different harvesting regimes using a labor time classification based model. Präsentation auf der Konferenz RRR2017.

Dahms, T., Oehmke, C., Kowatsch, A., Abel, S., Wichmann, S., Wichtmann, W. & Schröder, C. (2017): Paludi-Pellets-Broschüre. Halmgutartige Festbrennstoffe aus nassen Mooren. (Paludi pellets brochure. Stalk-type solid fuels from wet peatlands) 2. Auflage. Universität Greifswald. Greifswald.

Daun, C., Gaudig, G., Günther, A., Huth, V., Jacobs, O., Krebs, M. & Jurasinski, G. (2023): Full-cycle greenhouse gas balance of a Sphagnum paludiculture on former bog grassland in Germany. The Science of The Total Environment 877:162943

Deutscher Bundestag (2020): Antwort der Bundesregierung auf die Kleine Anfrage der Abgeordneten Steffi Lemke, Uwe Kekeritz, Harald Ebner, weiterer Abgeordneter und der Fraktion BÜNDNIS 90/DIE GRÜNEN – Drucksache 19/22377 – Sojaimporte nach Deutschland. (Answer by the Federal Government to the minor interpellation by Steffi Lemke, Uwe Kekeritz, Harald Ebner, other MPs and the Alliance 90/The Greens parliamentary group - printed matter 19/22377 - Soy imports to Germany) https://dserver.bundestag.de/btd/19/233/1923345.pdf

Dietz, W., Dornack, C., Schramm, S., Schütt, F. & Sieger, F. (2014): Ersatz klassischer Faserstoffe durch biogene Reststoffe Teil 1 und Teil 2 (Replacement of traditional fibers with biogenic waste materials), Wochenblatt für Papierfabrikation 4/2014 und 5/2014.

DLG (2020): Andelsselskaber vil producere grønt protein i Vestjylland. https://www.dlg.dk/da/Om-DLG/Presse/Nyheder/2020/05/Andelsselskaber_vil_ producere_gront_protein_i_Vestjylland

Doderer, H., Feldmüller, J. & Schäfer-Stradowsky, S. (2016): Hindernisse und Handlungsempfehlungen zur energetischen Nutzung von Paludikulturen. (Obstacles and recommendations for the energetic use of paludicultures) Endbericht. IKEM, Berlin, Greifswald. 99 S.

Dragoni, F., Giannini, V., Ragaglini, G., Bonari, E. & Silvestri, N. (2017): Effect of Harvest Time and Frequency on Biomass Quality and Biomethane Potential of Common Reed (Phragmites australis) Under Paludiculture Conditions. BioEnergy Research 10, 1066–1078.

Dürr, H.-J., Petelkau, H. & Sommer, C. (1995): Literaturstudie Bodenverdichtung. (Literature study on soil compaction) Umweltbundesamt. UBA-Texte 55/95, 203 S.

DVL & GMC (2022): Zusammenarbeit im Moor – so kommt der Klimaschutz voran! (Cooperation in peatlands - this is how climate protection makes progress!) Deutscher Verband für Landschaftspflege e.V. und Greifswald Moor Centrum. Ansbach und Greifswald, 20 S.

El Bassam, N. (2010): Handbook of Bioenergy Crops. A Complete Reference to Species, Development and Applications. Earthscan. London, Washington, DC. 545 S.

Eller, F., Ehde, P.M., Oehmke, C., Ren, L., Brix, H., Sorrell, B.K. & Weisner, S.E.B. (2020): Biomethane Yield from Different European Phragmites australis Genotypes, Compared with Other Herbaceous Wetland Species Grown at Different Fertilization Regimes. Resources, 9, 57.

Emsens, W.-J., Aggenbach, C. J. S., Smolders, A. J. P., Zak, D. & van Diggelen, R. (2017): Restoration of endangered fen communities: the ambiguity of iron-phosphorus binding and phosphorus limitation. Journal of Applied Ecology, 54, 1755–1764.

Finell, M. (2003): The Use of Reed Canary-Grass (Phalaris arundinacea) as a Short Fibre Raw Material for the Pulp and Paper Industry. Doctoral Thesis, Swedish University of Agricultural Sciences. Umea. 53 S.

Finkenstein, B. v. & Gerst, J. (2013): Forstökonomische Überlegungen zur Bewirtschaftung nasser Waldstandorte. (Forest economic considerations for the management of wet forest sites) AFZ-Der Wald 68 (18), S. 20 – 22.

FNR (2014): Marktanalyse Nachwachsende Rohstoffe. (Market analysis of renewable raw materials) Fachagentur Nachwachsende Rohstoffe (Hrsg.) Gülzow-Prüzen. 1119 S.

FNR (2020): Basisdaten Biobasierte Produkte 2021. (Basic data for bio-based products 2021) Fachagentur Nachwachsende Rohstoffe, Gülzow-Prüzen. 13 S.

Fraunhofer-Institut für Solare Energiesystem (2022): Agri-Photovoltaik: Chance für Landwirtschaft und Energiewende. (Agri-photovoltaics: an opportunity for agriculture and the energy transition) Ein Leitfaden für Deutschland. 2. Auflage. 76 S.

Frühschutz, L. (2020): Woher kommt Bio-Soja? (Where does organic soy come from?) Online Artikel auf Schrot & Korn. https://schrotundkorn.de/ essen/woher-kommt-bio-soja

Gaudig, G., Krebs, M. & Joosten, H. (2017): Sphagnum farming on cut-over bog in NW Germany: Long-term studies on Sphagnum growth. Mires and Peat, 20(4), 1-19.

Gaudig, G., Krebs, M., Prager, A., Wichmann, S., Barney, M., Caporn, S. et al. (2018): Sphagnum farming from species selection to the production of growing media: a review. Mires and Peat 20 (2017/18), S. 1-30.

Geurts, J., Oehmke, C., Lambertini, C., Eller, F., Sorrell, B., Mandiola, S., Grootjans, A., Brix, H., Wichtmann, W., Lamers, L. & Fritz, C. (2020): Nutrient removal potential and biomass production by Phragmites australis and Typha latifolia on European rewetted peat and mineral soils. Science of the Total Environment 747.

GMC (2019): Faktenpapier Rohrwerbung in Mecklenburg-Vorpommern. Rohrwerbung ist aussterbendes UNESCO-Kulturerbe – Potential für regionale Wertschöpfung und Umweltschutz kaum genutzt. (Fact paper on reed cutting in Mecklenburg-Vorpommern. Reed cutting is a dying UNESCO cultural heritage - potential for regional value creation and environmental protection hardly used) Greifswald Moor Centrum mit Rohrdachdeckerinnung M-V, Rohrdachdeckerei & Zimmerei Paech, Rohrwerbung & Verkauf H. Nordt. Greifswald. 4 S.

GMC (2022): Informationspapier des Greifswald Moor Centrum zu Photovoltaik-Anlagen auf Moorböden. (Information paper of the Greifswald Mire Centre on photovoltaic systems on peat soils) Greifswald Moor Centrum, Stand 03/2022.

GMC (2022b): Steckbriefe „Produkte aus Paludikultur". (Fact sheets "Products from paludiculture") Greifswald Moor Centrum. https://www.succow- stiftung.de/mokli (accessed 13.07. 2022)

GMC & DVL (2021): Vorgaben zum Grünlanderhalt bei der Umstellung auf Paludikultur. (Guidelines for maintaining grassland when converting to paludiculture) Informationspapier. Greifswald Moor Centrum, 9 S.

Götz, M., Rudi, A., Heck, R., Schultmann, F. & Kruse, A (2022): Processing Miscanthus to high value chemicals: A techno-economic analysis based on process simulation. GCB Bioenergy, 14, 447– 462.

Gramoflor (2020): Torfersatzstoff aus Rohrkolben und Schilf? (Peat substitute made from cattail and reeds?) Vortrag auf der Online Veranstaltung „Nach- wachsende Rohstoffe aus vernässten Mooren – eine Chance für den niedersächsischen Moor- und Klima- schutz?“ am 10.9.2020.

Günther A., Barthelmes, A., Huth, V., Joosten, H., Jurasinsky, G., Koebsch, F. & Couwenberg, J. (2020): Prompt rewetting of drained peatlands reduces climate warming despite methane emissions. Nature Communications, 11, 1644.

Haberl, A., Schroeder, P. & Schröder, C. (2016): Flächenverfügbarkeit. (Area availability.) In: Wichtmann et al. (Hrsg.): Palu- dikultur – Bewirtschaftung nasser Moore. Schweizer- bart'sche Verlagsbuchhandlung, Stuttgart, S. 179-181.

Haldan, K., Köhn, N., Hornig, A., Wichmann, S., & Kreyling, J. (2022): Typha for paludiculture—Suitable water table and nutrient conditions for potential biomass utilization explored in mesocosm gradient experiments. Ecology and Evolution, 12, e9191.

Hartung, C. & Eickenscheidt, T. (2018): Verwertung von Niedermoor-Paludikultur-Pflanzen als Biogas- Substrat und Torfersatzstoff (Utilization of fen paludiculture plants as biogas substrate and peat substitute), PowerPoint Präsentation, 13.07.2018.

Hartung, C., Andrade, D., Dandikas, V., Eickenscheidt, T., Drösler, M., Zollfrank, C. & Heuwinkel, H. (2020): Suitability of paludiculture biomass as biogas substrate – biogas yield and long-term effects on anaerobic digestion. Renewable Energy, 159, 64-71.

Hartung, C. & Meinken, E. (2021): Fen plant biomass as growing media constituent – reduction of nitrogen immobilization by composting. Acta Horticulturae, 1317.

Herrmann C., Prochnow A., Heiermann M. & Idler C. (2014): Biomass from landscape management of grassland used for biogas production: effects of har- vest date and silage additives on feedstock quality and methane yields. Grass and Forage Science, 69 (4), 549-566.

Hinzke, T., Tanneberger, F., Aggenbach, C., Dahlke, S., Knorr, K.-H., Kotowski, W., Kozub, W., Lange, J., Li, G., Pronin, E., Seeber, E., Wichtmann, W. & Kreyling, J. (2021): Can nutrient uptake by Carex counteract eutrophication in fen peatlands? Science of the Total Environment, 785.

Hirschelmann, S., Raschke, I., Stüber, M., Wichmann, S. & Peters, J. (2020): Moorschutz in der Gemeinsamen Agrarpolitik – Instrumente für eine klimaverträgliche Moornutzung in Deutschland. (Peatland protection in the Common Agricultural Policy - Instruments for climate-friendly peatland use in Germany) In: Berichte über Landwirtschaft, Band 98, Ausgabe 3.

Hofer, B. & Pautz, B. (2005): Integriertes Gebiets- und Entwicklungskonzept Hankhauser Moor. (Integrated area and development concept Hankhauser Moor)

Höller, M., Lunze, A., Wever, C., Deutschle, A.L., Stücker, A., Frase, N., Pestsova, E., Spiess, A.C., Westhoff, P. & Pude, R. (2021): Meadow hay, Sida hermaphrodita (L.) Rusby and Silphium perfoliatum L. as potential non-wood raw materials for the pulp and paper industry. Industrial Crops & Products, 167.

Holsten, B. & Trepel, M. (2016): Nährstoffhaushalt und Gewässerschutz. (Nutrient balance and water protection) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 106-108.

Horn, R. (1984): Die Vorhersage des Eindringwiderstandes von Böden anhand von multiplen Regressionsanalysen. (Predicting the penetration resistance of soils using multiple regression analysis) Zeitschrift für Kulturtechnik und Flurbereinigung, 25, 377–380.

Institute for Bioplastics and Biocomposites (2021): Biopolymers, facts and statistics 2021. Edition 8. Hochschule Hannover, 66 S.

Isermeyer F., Heidecke, C., Osterburg, B. (2019): Einbeziehung des Agrarsektors in die CO_2-Bepreisung. (Integration of the agricultural sector in CO_2 pricing) Thünen Working Paper 136. Johann Heinrich von Thünen-Institut. Braunschweig.

Joosten, H., Brust, K., Couwenberg, J., Gerner, A., Holsten, B., Permien, T., Schäfer, A., Tanneberger, F., Trepel, M. & Wahren, A. (2013): MoorFutures®: Integration von weiteren Ökosystemdienstleistungen einschließlich Biodiversität in Kohlenstoffzertifikate. Standard, Methodologie und Übertragbarkeit in andere Regionen. (MoorFutures®: Integration of other ecosystem services including biodiversity into carbon credits. Standard, methodology and transferability to other regions) BfN-Skripten 350. Bundesamt für Naturschutz, Bonn-Bad Godesberg.

Joseph, B., Kaetzl, K., Hensgen, F., Schäfer, B. & Wachendorfer, M. (2020): Sustainability assessment of activated carbon from residual biomass used for micropollutant removal at a full-scale wastewater treatment plant. Environmental Research Letters, 15 (6).

Jurasinski, G., Günther, A., Huth, V., Couwenberg, J. & Glatzel, S. (2016): Treibhausgasemissionen. (GHG emissions) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 79-94.

Kaiser, M. & Tanneberger, F. (2021): Treibhausgase. (Greenhouse gases) In: Närmann et al. (2021): Klimaschonende, biodiversitätsfördernde Bewirtschaftung von Niedermoorböden. BfN-Skripten 616.

Kaphengst, T., Prochnow, A. & Hampicke, U. (2005): Ökonomische Analyse der Rinderhaltung in halboffenen Weidelandschaften – Volks- und betriebswirtschaftliche Kostenanalyse aus sechs Gebieten. (Economic analysis of cattle farming in semi-open pasture landscapes - economic and business cost analysis from six areas) Naturschutz und Landschaftsplanung 37, 369–375.

Köbbing, J. (2016): China – Papier aus dem Wasser. (China - Paper from the water) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 223 – 226.

Korthorst, M. (2022): Paludicultuur in de Praktijk. Ervaringen in het IPV in de periode 2018-2021. Hrsg. v. Landschap Noord-Holland, Heiloo. 48 S.

Kraschinski, S., Prochnow, A., Tölle, R. & Hahn, J. (1999): Verfahrenstechnische Arbeiten zur Befahrbarkeit von Niedermoorgrünland. (Process engineering work on the navigability of fen grassland) In: Prochnow, A. (Hrsg.): Angepasstes Befahren von Niedermoorgrünland. Landschaftspflege in der Nuthe-Nieplitz-Niederung 3. Landschafts-Fördervereins Nuthe-Nieplitz-Niederung e.V., Stücken: 35–57.

Kratz, R. & Pfadenhauer, J. (Hrsg.) (2001): Ökosystemmanagement von Niedermooren. Strategien und Verfahren zur Renaturierung. (Ecosystem management of fens. Strategies and procedures for renaturation) Ulmer Verlag, Stuttgart, 317 S.

KTBL (2005): Landschaftspflege 2005. (Landscape management 2005) KTBL-Datensammlung, 5., überarbeitete Auflage. Kuratorium für Technik und Bauwesen in der Landwirtschaft. Darmstadt.

KTBL (2010): Planungsdaten für die Haltung von Wasserbüffeln. (Planning data for water buffaloes husbandry) Fachartikel. Kuratorium für Technik und Bauwesen in der Landwirtschaft Darmstadt. 18 S.

KTBL (2018): Faustzahlen für die Landwirtschaft (estimated figures for agriculture), 15. Auflage. Kuratorium für Technik und Bauwesen in der Landwirtschaft, Darmstadt, 1385 S.

Lahtinen, L., Mattila, T., Myllyviita, T., Seppälä, J. & Vasander, H. (2022): Effects of paludiculture products on reducing greenhouse gas emissions from agricultural peatlands. Ecological Engineering, 175, 106502.

Land, M., Granéli, W., Grimvall, A., Hoffmann, C.C.; Mitsch, W.J., Tonderski, K.S. & Verhoeven, J.T.A. (2016): How effective are created or restored freshwater wetlands for nitrogen and phosphorus removal? A systematic review. Environmental Evidence, 5, Nr. 9.

Landgraf, L. (2018): Wiedervernässung von Mooren. (Rewetting of peatlands) In: Luthardt, V. & Zeitz, J. (Hrsg.): Moore in Berlin und Brandenburg. Natur+Text, Rangsdorf, S. 239-250.

Lenz, A. (2001): Wassermanagement, Wassermengenbilanz und Nährstoffrückhaltefunktion wiedervernässter Niedermoorflächen. (Water management, water quantity balance and nutrient retention function of rewetted fens) In: Pfadenhauer, J. & Wild, U (Hrsg.): Rohrkolbenanbau in Niedermooren. Integration von Rohstoffgewinnung, Wasserreinigung und Moorschutz zu einem nachhaltigen Nutzungskonzept. Abschlussbericht zum DBU-Projekt Nr. 10628. Freising- Weihenstephan, TU München, S. 41-54.

LfU Brandenburg (2004): Leitfaden zur Renaturierung von Feuchtgebieten in Brandenburg. (Guidelines for the restoration of wetlands in Brandenburg) Studien und Tagungsberichte, Band 50. Landesumweltamt (LfU) Brandenburg, Potsdam, 193 S.

Limberg, J. (2022): AUKM-Programm “Moorschonende Wasserhaltung” – Erste Erfahrungen & Ergebnisse. (AECM program “peatland friendly water retention” - First experiences & results.) LIFE Limicodra. 20 S.

Liu, J., Kopold, P., van Aken, P., Maier, J. & Yu, Y. (2015): Energy Storage Materials from Nature through Nanotechnology: A Sustainable Route from Reed Plants to a Silicon Anode for Lithium-Ion Batteries. Angewandte Chemie, 54 (33), 9632-9636.

LM M-V (2000): Richtlinie zur Mahd von Schilfrohr in Röhrichten (Rohrwerbung). (Directive for cutting reed in reedbeds) Bekanntmachung des Umweltministeriums vom 21. August 2000, X 210-1 5326.61, AmtsBl. M-V 2000. S. 1175.

LM M-V (2017a) (Hrsg.): Umsetzung von Paludikultur auf landwirtschaftlich genutzten Flächen in Mecklenburg-Vorpommern. (Implementation of paludiculture on agricultural land in Mecklenburg-Western Pomerania) Fachstrategie zur Umsetzung der nutzungsbezogenen Vorschläge des Moorschutzkonzeptes. Ministerium für Landwirtschaft und Umwelt Mecklenburg-Vorpommern. Schwerin.

LM M-V (2017b): Richtlinie zur Förderung der dauerhaften Umwandlung von Ackerflächen in Dauergrünland: Acker/Dauergrünland-Umwandlungsrichtlinie. (Directive on the promotion of the permanent conversion of arable land into permanent grassland: Arable land/ permanent grassland conversion directive) Vom 5. April 2017 (AmtsBl. M-V 2017 S. 328). Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz Mecklenburg-Vorpommern.

Luthardt, V. & Zeitz, J. (2018): Prozesse und Auswirkungen einer entwässerungsbasierten Moornutzung. (Processes and effects of drainage-based peatland use) In: Luthardt, V. & Zeitz, J. (Hrsg.): Moore in Berlin und Brandenburg. Natur+Text, Rangsadorf, S. 113-122.

MacKinnon, A. (2009): Edible and Medicinal Plants of Canada. Lone Pine Publishing, Edmonton, 448 S.

Meier, D. (2014): Wärme vom Niedermoor. (Heat from peatlands) Energie aus Pflanzen 4/2014, S. 34-37.

MLUK (2023): Brandenburgs Moore klimafreundlich bewirtschaften – ein Ratgeber für Anwender und Interessierte. (Climate-friendly management of Brandenburg's peatlands - a guide for users and interested parties) Michael Succow Stiftung im Auftrag für Ministerium für Landwirtschaft, Umwelt und Klimaschutz (MLUK). Potsdam/Greifswald.

Müller, J. & Sweers, W. (2016): Produktion von Futter in Paludikultur. (Fodder production in paludiculture) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 39–43.

Muster, C., Gaudig, G., Krebs, M. & Joosten, H. (2015): Sphagnum farming: the promised land for peat bog species? Biodiversity and Conservation, 24, 1989–2009.

Närmann, F. (2018): Impacts of machine mowing on selected soil properties in near-natural fens. A case study from north-eastern Germany. Master Thesis. Unversität Greifswald. 32 S.

Närmann, F. & Tanneberger, F. (2021): Biodiversität. (Biodiversity) In: Närmann et al. (Hrsg.): Klimaschonende, biodiversitätsfördernde Bewirtschaftung von Niedermoorböden. BfN-Skripten 616. S. 154-182.

Närmann, F., Birr, F., Kaiser, M., Nerger, M., Luthardt, V., Zeitz, J. & Tanneberger, F. (2021): Klimaschonende, biodiversitätsfördernde Bewirtschaftung von Niedermoorböden. (Climate-friendly, biodiversity-promoting management of fen soils) BfN-Skripten 616, Bundesamt für Naturschutz, Bonn-Bad Godesberg, 341 S.

Negassa, W., Michalik, D., Klysubun, W. & Leinweber, P. (2020): Phosphorus speciation in long-term drained and rewetted peatlands of Northern Germany. Soils Systems 4 (1)

Nerger, M. & Zeitz, J (2021): Flächenkulisse. (Area backdrop) In: Närmann et al. (Hrsg.): Klimaschonende, biodiversitätsfördernde Bewirtschaftung von Niedermoorböden, BfN-Skripten 616, S. 97-134.

Neubert, J., Köhn, N., Haldan, K., Kuprina, K. & Wichmann, S. (2022): Paludikultur in die Praxis bringen: Integration – Management – Anbau. (Putting paludiculture into practice: Integration - Management - Cultivation) Schlussbericht zum Projekt Paludi-PRIMA. Universität Greifswald, 82 S.

Nielsen, C.K., Stødkilde, L., Jørgensen, U. & Lærke, P.E. (2021): Effects of harvest and fertilization frequency on protein yield and extractability from flood-tolerant perennial grasses cultivated on a fen peatland. Frontiers in Environmental Science, 9, 619258.

Nordt, A. & Doderer, H. (2017): Impulspapier: Verwertung von Paludikultur-Biomasse. Rechtliche Handlungsempfehlungen für die energetische und stoffliche Verwertung von Paludikultur-Biomasse. (Impulse paper: Utilization of paludiculture biomass. Legal recommendations for the energetic and material utilization of paludiculture biomass) Hrsg. v. Greifswald Moor Centrum (GMC) und Institut für Klimaschutz, Energie und Mobilität (IKEM).

Nordt, A., Abel, S., Eberts, J., Hoffmann, T., Kost, A., Lampe, M., Peters, J. & Wichtmann, W. (2020): Machbarkeitsstudie Aufwuchsverwertung und Artenvielfalt in der Leader-Region „Kulturlandschaften Osterholz". (Feasibility study on the utilization of vegetation and biodiversity in the Leader region "Kulturlandschaften Osterholz") Micheal Succow Stiftung im Auftrag des Landvolk Niedersachsen, Greifswald, 175 S.

Nordt, A. & Dahms, T. (2021): Paludi-tiny house – a demonstrator for climate friendly building materials. Poster auf der RRR2021 Konferenz 2021.

Nordt, A., Wichmann, S., Risse, J., Peters, J. & Schäfer, A. (2022): Potenziale und Hemmnisse für Paludikultur. Hintergrundpapier zur Studie „Anreize für Paludikultur zur Umsetzung der Klimaschutzziele 2030 und 2050“. (Potentials and obstacles for paludiculture. Background paper to the study “Incentives for paludiculture to achieve the climate protection targets for 2030 and 2050”) Hrsg. v. Deutsche Emissionshandelsstelle im Umweltbundesamt (DEHSt). Berlin.

Oehmke, C. & Abel, S. (2016): Ausgewählte Paludikulturen. (Selected paludicultures) In: Wichtmann et al. (Hrsg.): Paludikultur - Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 22-38

Pfadenhauer, J. & Wild, U. (Hrsg.) (2001): Rohrkolbenanbau in Niedermooren – Integration von Rohstoffgewinnung, Wasserreinigung und Moorschutz zu einem nachhaltigen Nutzungskonzept. (Cattail cultivation in fens - integration of raw material extraction, water purification and peatland protection into a sustainable utilization concept) Abschlussbericht zum DBU-Projekt Nr. 10628. Technische Universität München, Freising-Weihenstephan. S. 97–111.

Pfister, S. & Oppermann, R. (2021): Ökonomie. (Economics) In: Närmann et al. (Hrsg.): Klimaschonende, biodiversitätsfördernde Bewirtschaftung von Niedermoorböden. BfN-Skript 616, S. 183 – 199.

Pijlmann, J., Geurts, J.J.M., Vroom, R.J.E., Bestman, M., Fritz, C. & Eekeren, N. Van (2019): The effects of harvest date and frequency on the yield, nutritional value and mineral content of the paludiculture crop cattail in the first year after planting. Mires and Peat, 25(04).

Pijnakker, J., Arijs, Y., de Souza, A., Cellier, M. & Wäckers, F. (2015): The use of Typha angustifolia (cattail) pollen to establish the predatory mites Amblyseius swirskii, Iphiseius degenerans, Euseius ovalis and Euseius gallicus in glasshouse crops. Conference Paper. 5th Meeting of the working group “Integrated Control of mite pest” from September 8th to 10th 2015 in Castelló de la Plana, Spain.

Prochnow, A. & Kraschinski, S. (2001): Angepasstes Befahren von Niedermoorgrünland. (Adapted driving on fen grassland) Merkblatt 323. Hrsg. v. Deutsche Landwirtschafts-Gesellschaft (DLG). Berlin, Frankfurt. 16 S.

Quinty, F. & Rochefort, L. (2003): Peatland Restoration Guide, Second Edition. Canadian Sphagnum Peat Moss Association (St. Albert, AB) & New Brunswick Department of Natural Resources and Energy (Fredericton, NB), Canada, 106 S.

Ren, L., Eller, F., Lambertini, C., Guo, W.-Y., Brix, H. & Sorrell, B.K. (2019): Assessing nutrient responses and biomass quality for selection of appropriate paludiculture crops. Science of the Total Environment, 664, 1150 – 1161.

Röhe, P. & Schröder, J. (2010): Grundlagen und Empfehlungen für eine nachhaltige Bewirtschaftung der Roterle in Mecklenburg-Vorpommern. (Principles and recommendations for the sustainable management of alder in Mecklenburg-Western Pomerania) Drönnewitz: Waldbesitzerverband für Mecklenburg-Vorpommern e. V. 58 S.

Roj-Rojewski, S., Wysocka-Czubaszek, A., Czubaszek, R., Kamocki, A. & Banaszuk, P. (2019): Anaerobic digestion of wetland biomass from conservation management for biogas production. Biomass and Bioenergy 122, 126-132.

Roth, S., Seeger, T., Poschlod, P., Pfadenhauer, J. & Succow, M. (2001): Etablierung von Röhrichten und Seggenrieden. (Establishment of reedbeds and sedge meadows) In: Kratz, R., Pfadenhauer, J. (Hrsg.): Ökosystemmanagement von Niedermooren. Strategien und Verfahren zur Renaturierung: Ulmer Verlag, Stuttgart, S. 125 – 134.

Rühs, M. & Stein-Bachinger, K. (2018): Honorierung von Naturschutzleistungen (Remuneration for nature conservation services) Aktualisierte Neuauflage, 92 S.

Sasmaz, A., Öbek, E. & Hasar, H. (2008): The accumulation of heavy metals in Typha latifolia L. grown in a stream carrying secondary effluent. Ecological Engineering, 33, 278–284.

Schäfer, A. (2016): Volkswirtschaftliche Aspekte der Moornutzung. (Economic aspects of peatland use) In: Wichtmann, W., Schröder, C. & Joosten, H. (Hsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 133-142

Schäfer, A. & Joosten, H. (Hrsg.) (2005): Erlenaufforstung auf wiedervernässten Niedermooren (Alder afforestation on rewetted fens) - ALNUS Leitfaden. DUENE e.V., Greifswald, 68 S.

Schäfer, J. & Yilmaz, Y. (2019): Aktuelle Hemmnisse und Weiterentwicklungsoptionen im Ordnungs- und Planungsrecht zugunsten der Moorrevitalisierung als Umsetzung von Klimaanpassungs- und Klimaschutzmaßnahmen. (Current obstacles and further development options in regulatory and planning law in favour of peatland revitalization as an implementation of climate adaptation and climate protection measures) Rechtwissenschaftliche Studie. Greifswald Moor Centrum-Schriftenreihe 04/2019.

Schäfer, A., Nordt, A., Peters, J. & Wichmann, S. (2022): Anreize für Paludikultur zur Umsetzung der Klimaschutzziele 2030 und 2050. (Incentives for paludiculture to achieve the 2030 and 2050 climate protection targets) Umweltbundesamt. Climate Change 44/2022.

Schätzl, R., Schmitt, F., Wild, U. & Hoffmann, U. (2006): Gewässerschutz und Landnutzung durch Rohrkolbenbestände. (Water protection and land use through cattail stands) Wasserwirtschaft, 96, S. 24–27.

Schlattmann, A. & Rode, M. (2019): Spatial potential for paludicultures to reduce agricultural greenhouse gas emissions: an analytic tool. Mires and Peat, 25 (03), 1–14.

Schmidt, W. (1980): Zur Bestimmung der Scherfestigkeit von Torfen und Mudden. (For determining the shear strength of peat and gyttja) Wissenschaftlich-technische Informationen für das Meliorationswesen 61, 28–41.

Schmidt, W. (1995): Einfluss der Wiedervernässung auf physikalische Eigenschaften des Moorkörpers der Friedländer Großen Wiese. (Influence of rewetting on the physical properties of the peat body of the Friedländer Große Wiese) Zeitschrift für Kulturtechnik und Landentwicklung, 36, 107–122.

Schmilewski, G. (2017): Growing media constituents used in the EU in 2013. Acta Horticulturae, 1168, 85–92.

Scholwin, F. & Siegert, G. (2020): Biogas aus Paludikulturen – Produktionsweg, Hintergründe, Klimaschutzwirkung. (Biogas from paludicultures - production route, background, climate protection effect.) Greenpeace Energy eG.

Schreiner, B.-G. (1967): Technique for estimating the performance of tracked vehicles in muskeg. Journal of Terramechanics, 4, 23–29.

Schröder, C., Dahms, T., Paulitz, J., Wichtmann, W. & Wichmann, S. (2015): Towards large-scale paludiculture: addressing the challenges of biomass harvesting in wet and rewetted peatlands. Mires and Peat, 16, 13.

Schröder, C. & Dettmann, S. (2016): Realisierbarkeit der Ernte von Biomasse aus Paludikultur. (Feasibility of harvesting biomass from paludiculture) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 77–78.

Schröder C., Dettmann, S., Wichmann S. (2016): Logistik der Biomasseproduktion auf nassen Mooren.

(Logistics of biomass production on wet peatlands) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 70-76.

Schröder, C., Nordt, A. & Bork, L. (2017): Entwicklung einer klimagerechten regionalen Energieversorgung durch Paludikultur am Beispiel des Landkreises Vorpommern-Rügen. (Development of a climate-friendly regional energy supply through paludiculture using the example of the district of Vorpommern-Rügen) BMEL-Modellvorhaben Land(auf)Schwung. DUENE e.V., Greifswald, 38 S.

Schröder, C., Hohlbein, M., Wichmann, S., Busse, S., Wichtmann, W. & Tanneberger, F. (2019): Identifizierung von landwirtschaftlich genutzten Mooren, die für die Einrichtung von Demonstrationsflächen für Paludikultur in Mecklenburg-Vorpommern geeignet sind. (Identification of agriculturally used peatlands suitable for the establishment of demonstration areas for paludiculture in Mecklenburg-Western Pomerania) DUENE e.V., Partner im Greifswald Moor Centrum im Auftrag des Ministeriums für Landwirtschaft, Umwelt und Verbraucherschutz Mecklenburg-Vorpommern. Endbericht, unveröffentlicht.

Schulze, P., Schröder, C., Luthardt, V. & Zeitz, J. (2016): Das Entscheidungsunterstützungssystem TORBOS. (The TORBOS decision support system) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 184-188.

Steinbach, D., Kruse, A. & Sauer, J. (2017): Pretreatment technologies of lignocellulosic biomass in water in view of furfural and 5-hydroxymethylfurfural production- A review. Biomass Conversion and Biorefinery 7(2).

Stiller, W. & Ohl, S. (2015): Untersuchung zur Feststoffvergärung von Landschaftspflegematerial niedersächsischer Grünlandstandorte. (Investigation of solid matter fermentation of landscape conservation material from grassland sites in Lower Saxony) Abschlussbericht 2014. Hochschule Hannover. Hannover.

Strauss, J. (2018): Funktionserweiterung von Faserguss-Formteilen durch Anpassung der Verfahrensbedingungen für die hochgradige Einbindung von funktionalen Füllstoffen. (Functional enhancement of molded fiber castings by adapting the process conditions for the high-grade integration of functional fillers) PTS-Forschungsbericht 08/18. Papiertechnische Stiftung, München. 32 S.

Succow, M. & Joosten, H. (2001): Landschaftsökologische Moorkunde. (Landscape ecology of peatlands) Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 623 S.

Sündermann, J., Schröder, J. & Röhe, P. (2013): Bodenschonende Holzernte in geschädigten Eschenbeständen auf Nassstandorten Erkenntnisse und Empfehlungen aus Fallstudien in Mecklenburg-Vorpommern. (Soil-conserving timber harvesting in damaged ash stands on wet sites. Findings and recommendations from case studies in Mecklenburg-Western Pomerania) Schwerin: Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz Mecklenburg-Vorpommern (LU), 44 S.

Sündermann, J. & Röhe, P. (2014): Vollmechanisierte Holzernteverfahren auf Nassstandorten. (Fully mechanized timber harvesting methods on wet sites) Landesforst Mecklenburg-Vorpommern, Malchin, 35 S.

Sweers, W., Möhring, T. & Müller, J. (2014): The economics of water buffalo (Bubalus bubalis) breeding, rearing and direct marketing. Archiv Tierzucht, 57, 22, 1–11.

Sweers, W. & Müller, J. (2016): Verwertung in der Tierhaltung. (Utilization in husbandry) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 116–118.

Tanneberger, T., Schröder, C., Hohlbein, M., Lenschow, U., Permien, T., Wichmann, S. & Wichtmann, W. (2020): Climate Change Mitigation through Land Use on Rewetted Peatlands – Cross-Sectoral Spatial Planning for Paludiculture in Northeast Germany. Wetlands, 40, 2309–2320.

Temmink, R.J.M., Fritz, C., van Dijk, G., Hensgens, G., Lamers, L.P.M., Krebs, M., Gaudig, G. & Joosten, H. (2017): Sphagnum farming in a eutrophic world: The importance of optimal nutrient stoichiometry. Ecological Engineering 98.

Theuerkorn, W. (2001): Rohrkolbenverwertung. (cattail utilization) In: Pfadenhauer, J. & Wild, U.: Rohrkolbenanbau in Niedermooren – Integration von Rohstoffgewinnung, Wasserreinigung und Moorschutz zu einem nachhaltigen Nutzungskonzept. Abschlussbericht zum DBU-Projekt Nr. 10628. Technische Universität München, Freising-Weihenstephan, S. 97-111.

Tiemeyer, B., Bechtold, M., Belting, M., Freibauer, A., Förster, C., Schubert, E., Dettmann, U., Frank, S., Fuchs, D., Gelbrecht, J., Jeuther, B., Laggner, A., Rosinski, E., Leiber-Sauheitl, K., Sachteleben, J., Zak, D. & Drösler, M. (2017): Moorschutz in Deutschland – Optimierung des Moormanagements in Hinblick auf den Schutz der Biodiversität und der Ökosystemleistungen: Bewertungsinstrumente und Erhebung von Indikatoren (Peatland protection in Germany - Optimization of peatland management with regard to the protection of biodiversity and ecosystem services: Assessment tools and collection of indicators), BfN-Skript 462, Bundesamt für Naturschutz, Bonn-Bad Godesberg, 319 S.

Tiemeyer, B., Freibauer, A., Albiac-Borraz, E., Augustin, J., Bechtold, M., Beetz, S., Beyer C., Ebli, M., Eickenscheidt, T., Fiedler, S., Förster, C., Gensior, A., Giebels, M., Glatzel, S., Heinichen, J., Hoffmann, M., Höper, H., Jurasinski, G., Laggner, A., Leiber-Sauheitl, K., et al. (2020): A new methodology for organic soils in national greenhouse gas inventories: Data synthesis, derivation and application. Ecological Indicators, 105838.

Türk, O. (2014): Stoffliche Nutzung nachwachsender Rohstoffe. (Material use of renewable raw materials) Springer Vieweg, S. 443–454.

UBA (2021): Berichterstattung unter der Klimarahmenkonvention der Vereinten Nationen und dem Kyoto-Protokoll 2021. Nationaler Inventarbericht zum Deutschen Treibhausinventar 1990-2019. (Reporting under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2021. National inventory report on the German Greenhouse Inventory 1990-2019) Umweltbundesamt, Dessau-Roßlau.

Vroom, R., Geurts, J., Nouta, R., Borst, A., Lamers, L. & Fritz, C. (2022): Paludiculture crops and nitrogen kick-start ecosystem service provisioning in rewetted peat soils. Plant Soil, 474, 337-354.

Wahren, A. (2016): Wasserbedarf für Paludikulturen am Beispiel Nordostdeutschland (Water requirements for paludiculture using the example of northeast Germany) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 191f.

Wahren, A., Brust, K., Dittrich, I. & Edom, F. (2016): Regionalklima und Landschaftswasserhaushalt. (Regional climate and landscape water balance) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 102–106.

Walton, C.R., Zak, D., Audet, J., Petersen, R.J., Lange, J., Oehmke, C., Wichtmann, W., Kreyling, J., Grygoruk, M., Jablonska, E., Kotowski, W., Wiśniewska, M.M., Ziegler, R. & Hoffmann, C.C. (2020): Wetland buffer zones for nitrogen and phosphorus retention: Impacts of soil type, hydrology and vegetation. Science of the Total Environment, 727, 138709.

Wenzel, M., Kabengele, G., Dahms, T., Barz, M. & Wichtmann, W. (2022): Bioenergie aus Mooren. Thermische Verwertung von halmgutartiger Biomasse aus

Paludikultur. (Bioenergy from peatlands. Thermal utilization of stalk-like biomass from paludiculture) Universität Greifswald, 58 S.

Wiche, O., Feuerstein, U. & Heilmann, H. (2021): Reed canary grass as a potential agent for phytoremediation and phytomining of strategic elements. Vortrag auf der Konferenz RRR2021.

Wichmann, S. (2016): Betriebswirtschaftliche Aspekte von Paludikultur. (Economic aspects of paludiculture) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 109–119.

Wichmann, S. (2017): Commercial viability of paludiculture: A comparison of harvesting reeds for biogas production, direct combustion, and thatching. Ecological Engineering 103, 497–505.

Wichmann, S. (2022): PRIMA – Erste Ernte im Rohrkolben-Praxisanbau bei Neukalen (D). (PRIMA - First harvest in demonstration cattail cultivation near Neukalen (GER)) In: Paludikultur-Newsletter 2022_01.

Wichmann, S. & Köbbing, J. (2015): Common reed for thatching - A first review of the European market. Industrial Crops and Products, 77, 1063–1073.

Wichmann, S., Dettmann, S. & Dahms, T. (2016): Landtechnik für nasse Moore. (Agricultural technology for wet peatlands) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 63-70.

Wichmann, S., Prager, A. & Gaudig, G. (2017): Establishing Sphagnum cultures on bog grassland, cut-over bogs, and floating mats: procedures, costs and area potential in Germany. Mires and Peat 20.

Wichmann, S., Krebs, M., Kumar, S. & Gaudig, G. (2020): Paludiculture on former bog grassland: Profitability of Sphagnum farming in North West Germany. Mires and Peat, 26, 1-18.

Wichmann, S., Nordt, A. & Schäfer, A. (2022a): Lösungsansätze zum Erreichen der Klimaschutzziele und Kosten für die Umstellung auf Paludikultur. Hintergrundpapier zur Studie „Anreize für Paludikultur zur Umsetzung der Klimaschutzziele 2030 und 2050". (Solutions for achieving climate protection targets and the costs of implementing paludiculture. Background paper on the study "Incentives for paludiculture to achieve the 2030 and 2050 climate protection targets".) Hrsg. v. Deutsche Emissionshandelsstelle im Umweltbundesamt (DEHSt). Berlin.

Wichmann, S., Reichelt, F. & Nordt, A. (2022b): Herleitung von Förderpauschalen zur Umsetzung von Moorklimaschutzprojekten. (Derivation of funding lump sums for the implementation of peatland climate protection projects) GMC-Schriftenreihe 01/2022.

Wichtmann, W. (1999): Schilfanbau als Alternative zur Nutzungsauflassung von Niedermooren. (Reed cultivation as an alternative to the abandonment of fens) Archiv für Naturschutz und Landschaftsforschung, 38, 97-110.

Wichtmann, W. & Schröder, C. (2016): Kulturtechnische Maßnahmen für die Umsetzung von Paludikultur. (Technical cultivation measures for the implementation of paludiculture) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 188–193.

Wichtmann, W., Schröder, C. & Joosten, H. (Hrsg.) (2016): Paludikultur - Bewirtschaftung nasser Moore. Klimaschutz - Biodiversität - regionale Wertschöpfung. (Paludiculture - productive use of wet peatlands) Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 272 S.

Wiedow, D., Burgstaler, J. & Schröder, C. (2016): Befahrbarkeit nasser und wiedervernässter Niedermoore. (Trafficability of wet and rewetted fen peatland) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 59–62.

Wijns, K., Van Ackere, C. & Aarts, R. (2018): Logistiek en machines van natuurgras tot verwerker. Rapport Gras-Goed. Natuurlijk Groen als Grondstof. Mechelen. 24 S.

Wilson, P. C., Whitwell, T. & Klaine, S. J. (2000): Metalaxyl and simazine toxicity to and Uptake by Typha latifolia. Archives of Environmental Contamination and Toxicology, 39 (3), 282–288.

Zak, D. & Gelbrecht, J. (2007): The mobilisation of phosphorus, organic carbon and ammonium in the initial stage of fen rewetting (a case study from NE Germany). Biogeochemistry, 85, 141–151.

Zak, D., Gelbrecht, J. Zerbe, S. Shatwell, T., Barth, M., Cabezas, A. & Steffenhagen, P. (2014): How helophytes influence the phosphorus cycle in degraded inundated peat soils: implications for fen restoration. Ecological Engineering, 66, 82–90.

Zielke, L. (2016): Rohrglanzgras vernässter Moorstandorte als Pferdefutter. (Reed canary grass from wet peatland sites as horse feed) In: Wichtmann et al. (Hrsg.): Paludikultur – Bewirtschaftung nasser Moore. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, S. 34.