Succow Foundation, Greifswald, Germany,
on behalf of UNDP in Ukraine

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UNDP

PALUDICULTURE

EU EXPERIENCE AND PROSPECTS FOR IMPLEMENTATION IN UKRAINE

COMPENDIUM

2024


Level fluctuations of water tables in Polissia fen peatland with low-intensity utilisation and relatively high water tables, caused by neglecting drainage system, Ukraine (Wichtmann 2010)


Too wet for low-intensity grazing, too dry for climate mitigation: a drained peatland in Polissia (Wichtmann 2010)

PALUDICULTURE, EU EXPERIENCE AND PROSPECTS FOR IMPLEMENTATION IN UKRAINE

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Greifswald, May 2024

Cover:

Buffaloes on Yermakiv Island, Odesa Oblast, captured by the Rewilding Ukraine team.

Photo by Maksym Yakovlev

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PREFACE

Jaco Cilliers,

Resident Representative of the United Nations Development Programme (UNDP) in Ukraine

IIn 2024, as Ukraine faces unprecedented war damages estimated in the trillions of hryvnias, we are confronted with both a significant challenge and a profound opportunity. While we cannot change the past, each of us holds the power to shape the future. The country is poised for comprehensive reconstruction, and it is our duty to ensure that future generations can enjoy a clean environment. This is achievable through the "Build Back Greener" approach, which promotes sustainable resource use, biodiversity conservation, and plays a critical role in shaping a national strategy rooted in environmental responsibility and minimizing the ecological impact of the war.

With the support of the Global Environment Facility and the FOLUR platform, the United Nations Development Programme (UNDP) is sharing expertise and assisting in implementing globally recognized environmentally focused practices, adapting them to Ukraine's unique context.

We are grateful to everyone who has chosen to adopt sustainable practices in their professional and daily activities. UNDP will continue to foster and support a culture of sustainability, which is an integral part of Ukraine's green recovery.

Roman SHAKHMATENKO,

Coordinator of the Energy and Environmental Protection Project Group of the United Nations Development Programme in Ukraine

2024 has been recognized as the year of climate dialogue in Ukraine. The country is obliged to ensure the implementation of the European Green Deal and the implementation of the Paris Agreement, one of the main goals of which is adaptation to climate change. In order to accelerate these processes, the Government this year approved the Strategy for the Formation and Implementation of State Policy in the Field of Climate Change until 2035 and the Operational Action Plan for 2024-2026. Almost simultaneously, the EU adopted a historic decision – the Nature Restoration Law, which sets the ambitious task of restoring the environment by 2050. This law establishes clear requirements for the restoration of various types of ecosystems, in particular agricultural lands, forests and urban ecosystems. Each EU country undertakes to take measures to restore drained peatlands (organic soils) in agriculture. In order to join the European community with dignity, Ukraine must now step by step adapt its legislation to the high standards of the European Union, and its citizens must gradually implement sustainable practices in their daily lives. It is important that to support this process, we must refer to successful examples from other countries.

This compendium collects valuable experience from EU countries in the application of paludiculture practices on restored peatlands, which looks like an excellent combination of an environmentally friendly solution with economic feasibility.

The Compendium is the first collection in Ukraine containing scientific information on paludiculture as a sustainable land use method being implemented in the countries of the European Union. It is important to note that for its successful implementation in Ukraine, adaptation of European experience to Ukrainian conditions, institutional capacity of the state and support of farmers are necessary. We realize that this is a long-term process that can be economically beneficial in the long term. However, it is this approach that will allow restoring natural ecosystems for the well-being of communities and achieving the defined goal within the framework of the green recovery course of Ukraine.

LIST OF ABBREVIATIONS

DPPP	Database of Potential Paludiculture Plants
EC	Eddy covariance
GEST	Greenhouse Gas Emission Site Type
HTC	Hydrothermal carbonization
ES	Ecosystem services
EU	European Union
SREP	Short-rotation energy plantations
VS	Volatile substances
NDC	Nationally determined contributions
LMU	Live mass unit
GHG	Greenhouse gases
UNDP	United Nations Development Programme
RBMP	River Basin Management Plan
DWP	Dry wood pulp
FAO	Food and Agriculture Organization of the United Nations
GMC	Greifswald Mire Centre
IBF	International Buffalo Federation
IPCC	The Intergovernmental Panel on Climate Change
LULUCF	Land use, land-use change, and forestry
VCS	Verified Carbon Standard
WWF	World Wild Fund for Nature

1. INTRODUCTION

This report was prepared under the mandate of the UNDP-GEF project "Promoting Sustainable Livestock Management and Ecosystem Conservation in Northern Ukraine". In preparing the compendium, we were guided by the document on the assessment of the potential of paludiculture in England and Wales, as this is the latest comprehensive study on this topic (Mulholland et al. 2020). However, this document does not take into account the huge number of publications that were made in 2020 or later.

We see our task as providing scientific information on paludiculture, a new direction of agricultural production on rewetted organic soils. This concept was developed to reduce greenhouse gas emissions from peatlands and, at the same time, further use of these areas after rewetting for profit. Therefore, in our study, we did not discuss other methods of using drained organic soils, as we understand that each specific territory and country is very different from each other, and the introduction of paludiculture means a significant paradigm shift in prioritizing the climate agenda, which is extremely difficult due to the current political, social and economic situation in Ukraine.

Since our task was to compile an updated literature review, and not an economic analysis of peatland management in Ukraine, an economic analysis of different paludiculture practices, the search for the most profitable and economically feasible options is beyond the scope of our work, although the most relevant thematic studies on peatland farming are supported by examples of cost-effectiveness calculations on the example of Germany. We hope that the UNDP project in Ukraine "Promoting Sustainable Livestock Management and Ecosystem Conservation in Northern Ukraine" will continue this work and find opportunities for economic analysis of different peatland farming options and the creation of pilot sites.

Our compendium is based on the document by Mulholland et al. (2020) and provides a useful structure, but there are differences between the documents, as some statements cannot be applied to Ukraine and some other statements are outdated. We would like to note that, as Ukraine is not a member of the EU, the framework conditions are different from those in the EU, as well as from those in the UK. This has implications for state subsidies, carbon markets, as well as irrigation practices and paludiculture projects.

1.1 Area and status of peatlands in Ukraine

Unfortunately, there is no current data on the area and distribution of peatlands in Ukraine, and the available literature contains contradictory data, since different peat thicknesses were used for classification, and the purpose of assessing the area of peatlands was different in each case.

The book "The Peat Fund of the Ukrainian SSR", published in 1959 (Ukraine already had its modern borders), indicates the presence of 1,146,300 hectares of total peat mires and 801,500 hectares of mires with a peat thickness of more than 50 cm. This was probably the most thorough study of peat mires (The Peat Fund of the Ukrainian SSR, 1959).

Ten years later, in 1969, an updated edition was published, which reported 575,900 hectares of peatlands with a peat thickness of more than 70 cm. 95% of the area of these territories was classified as eutrophic peatlands, 2.5% as oligotrophic, 2% as mesotrophic, and 0.5% as mixed (Provorkin, A. & Sidaskyi, A., 1969).

According to the data by State Committee of Ukraine for Geology and Subsoil Use as of 1999, the area of peatlands was 1,000,000 hectares, the area of industrial peat deposits with a peat thickness of more than 70 cm was 581,879 hectares (Movchan et al. 2017).

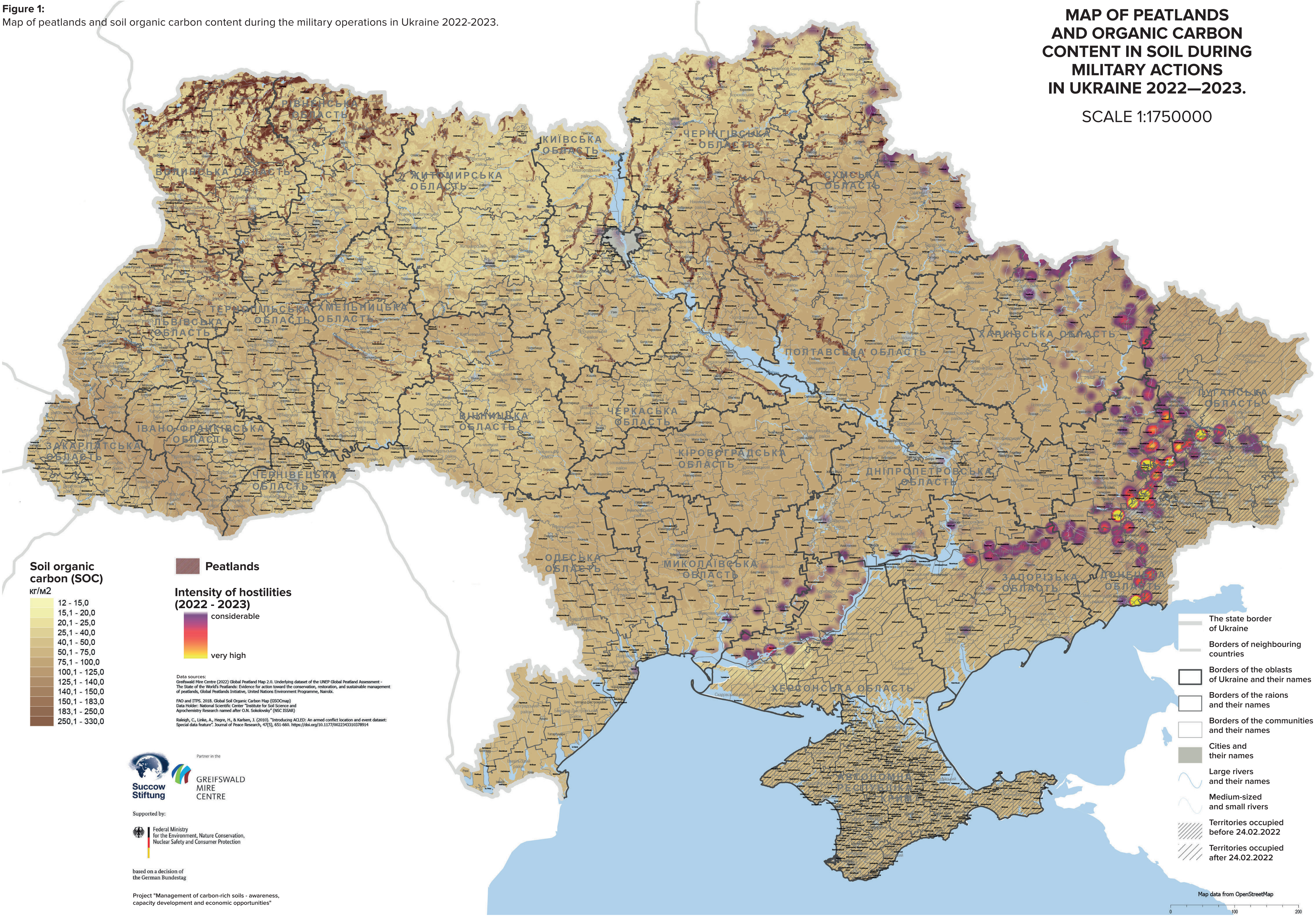
These data raise many questions, because in Ukraine during Soviet times, intensive drainage of peatlands was carried out for the needs of agriculture and forestry, peat was extracted, therefore the area of peatlands with industrial deposits could not increase or remain unchanged during the period from 1969 to 1999.

Unfortunately, the modern statistics system does not allow us to draw conclusions about the size of natural peat mires or peatlands, because there is no separate accounting of such territories. Thus, according to the State Service for Geodesy, Cartography and Cadastre, as of 1 January 2020, there were 973,800 hectares of open wetlands in Ukraine (Statistical Yearbook of Ukraine 2023), but some peat mires may be included in other categories of land.

In 1991, the area occupied by natural peat mires was estimated at 693,700 ha (Minaeva et al 2009). Today, this figure has decreased due to droughts, mining, peatland burning, the use of hydrotechnical land reclamation, etc. (Vozniuk et al. 2017).

Peatlands are concentrated in the north of the country, mainly in the Prypiat and Dnieper basins (see Figure 1). Smaller peatlands are located in the Carpathian Mountains, the estuary of Danube and other Black Sea estuaries.

Figure 1:
Map of peatlands and soil organic carbon content during the military operations in Ukraine 2022-2023.



1.2 Peatland use in Ukraine – from ancient times to the present

1.2.1 History of peatland use

From ancient times Ukrainian mires and peatlands have been used as pastures and for hay-making, hunting, and fishing. A large part of the diet of people living in or close to mires consisted of mushrooms and berries such as Vaccinium oxycoccos (small cranberry), Vaccinium microcarpum (small bog cranberry), Vaccinium myrtillus (bilberry), Vaccinium uliginosum (bog bilberry), Vaccinium vitis-idea (lingonberry), Rubus caesius (European dewberry), Rubus nessensis (ness bramble), and Ribes nigrum (black currant) (see Photo 1) which were collected in natural mires. A local flour was prepared from seeds and fruits of Glyceria maxima (reed mannagrass), Glyceria fluitans (water mannagrass), Trapa natans (water chestnut), from roots of Typha spp. (cattail), Nymphaea alba (white waterlily), and Butomus umbellatus (flowering rush). More than 20 species of medicinal plants can be collected from mires and are well-known by the locals. These include Menyanthes trifoliata (bog bean), Acorus calamus (sweet flag), Ledum palustre (marsh Labrador tea), Valeriana spp. (valeriana), Salix cinerea (grey willow), Cardamine palustris (cuckoo flower), Potentilla erecta (tormentil), Drosera rotundifolia (roundleaf sundew), Frangula alnus (alder buckthorn), Alnus glutinosa (common alder), Alnus incana (speckled alder), Polygonum hydropiper (water pepper), Orchis laxiflora ssp. Palustris (lax-flowered orchid), and Nuphar lutea (yellow pond lily). The bactericidal and hydroscopic properties of Sphagnum mosses are recognised and used widely. Unfortunately up to 40% of the area where edible resources were collected was lost due to the Chornobyl nuclear disaster (1986). Together with forests, mires form a natural unit and are part of the spiritual heritage. Mires are frequently included in Ukrainian fairy tales, folklore, literature, and art. They also have the potential to be an important recreation resource, but this has not been widely acknowledged and therefore the potential economic benefits have not been realised (Movchan et al. 2017).

Animal husbandry has long been an important way of utilising peatlands with low intensity. Either the grazing animals were fed with hay that was mown by hand in the wet meadows, or the ruminants adapted to the inhospitable conditions grazed in the peatlands in dry summers. In Central Europe this low intensity grassland management was widespread. The use of wild plants as straw (litter) or fodder (hay) has been traditionally common. Peatlands serve as wild pasture for domestic animals. Only slightly drained peatlands (water level -10-30 cm from the soil surface) are used for the production of litter or low quality hay (see Photo 3). However, this kind of low impact peatland use has been drastically decreasing during the last century; instead, large peatland areas have been completely drained (complex amelioration).

In Ukraine, drainage of mires began in the late 19th century. In 1873–1898, more than 4,700 km of drainage channels were constructed in Volyn, Rivne, and Zhytomyr Oblasts. The drained land was converted into pastures and hay meadows. By the beginning of XX century, most of the drained wetlands (c. 15,000 ha) had already been pipe-drained. A further 5,265 km of drainage channels were constructed in 1909–1914 and by 1917 c. 430,000 ha of mires had been drained, with the land being used as pastures. After 1917, the drainage rate decreased, but the total area of drained land increased. After World War II, there was an increase in drainage of mire systems. By 1966, 1.37 million ha of wetlands had been drained, and this figure increased to 2.06 million ha by 1976. In 1978, the total area of drained wetland totalled 2.25 million ha, including 613,900 ha of former mires (= c. 50% of the original mire area with peat deposits more than 70 cm (Movchan et al. 2017) (see Photo 4 and Photo 5).

Photo 4:
Traditional haymaking in wet peatlands in Ukrainian Polissia (Wichtmann 2010)

Photo 5:
Large scale complex amelioration in Ukrainian Polissia (Wichtmann 2010)

1.2.2 High intensity grassland

Drainage and intensive grassland utilization on peat soils for the production of high quality silage or hay requires similar hydrotechnical interventions as in old arable lands, e.g. for maize silage production. Correspondingly the peat soils of these sites are deeply affected by mineralization, shrinking, and soil compaction. Further drainage activities adapted the peatlands to the needs of industrialized production which made possible to produce maize and grasses for hay or silage with yields higher than on mineral soils. Due to fertilization and mineralisation of peat soils, that nutrients were never in short supply, and the intensively used grassland could be harvested 4-5 times a year. In Volyn and Rivne Oblasts alone, the area of drained lands during Soviet times amounted to 594,000 ha, but not all drained areas were peatlands (Vozniuk et al. 2017).

This kind of intensive land use on fen grasslands with three to five harvestings per year has lost its importance in Central Europe because of decreased soil productivity, but is still standard in other regions of Europe. It eventually became clear that the drainage of peatlands had more negative effects than positive benefits as fodder productivity decreased and arable land was quickly exhausted through the loss of humus as a result of wind and water erosion. Wind and water erosion of the topsoil in Polissia is extremely high, so the experts of the National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky" requested restoration of minimum 250,000 ha of the degraded peatlands (Movchan et al. 2017; Sytnyk V. & Truskavetskyi P. 2010).

High productivity grass species sowed on these degraded peat soils, damaged by previous intensive land use, cannot form stable grassland communities but are out-competed by twitch grass (Elymus repens) after four to five years. The resulting twitch grass stands show lower total performance, quality, and decreased digestibility for ruminants (Tanneberger and Wichtmann 2011). This necessitates regular ploughing (or a complete killing of the sward by herbicide application) and reestablishment of the desired high productivity grasses (Succow and Joosten 2001). Modern breeds of dairy cows with their ever increasing milk production require more and more high quality fodder that can only be produced on mineral soils. In Ukraine and in other countries, this has led to the agricultural abandonment of vast areas of peatlands.

Photo 6:
Drained peatlands in Ukrainian Polissia, ineffectively used as a pasture for milk cows (Bärisch 2010)

In the 1980s, 14–15 million tons of peat were extracted annually for use as "fertilisers" on fields and in greenhouses by local subsections of "Silhospkhimiia" ("Agricultural Chemistry"), resulting in a total peat extraction of 21–23 million tons per year. In the 1990s, peat extraction volumes decreased substantially due to economic changes. Up until 2010, pursuant to the State Energy Programme of Ukraine, c. 1.6 million tons of peat were extracted annually. Most Ukrainian peat, used as fuel and fertilizer, has an ash content of up to 35%. There are only 10 deposits of bituminous peat with an ash content of <10%, suitable for processing by hydrolysis.

In the 1980s peat was extracted predominantly by rotary cultivation. By the late 1990s, changed economics meant that the majority of peat was extracted by excavators, with consequently greater negative impacts on the natural hydrological patterns. Since the mid-1990s, Sphagnum peat has been widely used in horticulture for potting, substrate peat blocks, and nutritious peat briquettes. In other countries, peat from ombrotrophic mires was used to produce peat molasses, peat fodder sugar, fodder yeast etc. for cattle. "Peatland medicines" included Torfenal (for treatment of dermal diseases) and Torfot (for treatment of eye diseases). Exported peat volumes were small because of the dominance of low-quality peat and radioactive pollution following the Chornobyl disaster. The major peat markets are Germany, Greece, Egypt, France, Czech Republic, and Slovakia. After peat extraction, the land is subject to recultivation, i.e. it has to made useable for agriculture (arable land, pasture, haymaking), afforestation, or fishery (by building ponds). Building of fishponds was encouraged because it helped fulfil the Food Programme of the former USSR. Afforestation was promoted after completion of peat extraction (Movchan et al. 2017).

1.2.3 Low intensity grassland

In most peatland areas of Germany, Poland, as well in Polissia in Ukraine, low input use of peatlands often followed a period of more intensive agriculture, that had been given up because of various problems concerning maintenance of amelioration systems, decreasing carrying capacity of the soils, peat mineralisation, erosion and compaction of the soil.

Usually, these sites are managed by beef cattle grazing (c. one animal/ha), haymaking once or twice a year for or some combination of both. The hay is used e.g. for suckler cows[1] or young cattle with low performance. Fertilisation and phytosanitary measures are not common. In Germany these land use forms are only competitive because of subsidies. Nevertheless, this type of management is dependent on drainage as cattle as well as the heavy machinery used are dependent on water table heights to a maximum of 40–60 cm above soil surface.

This leads to the same problems that can be observed in intensive grassland management on peat soils.

Another problem of intensive use was plant species composition changes and decreasing productivity of the sites. Due to these problems and not least because of the changing political conditions and the collapse of large collective farms, the cultivation of large areas of moorland was even abandoned (Succow and Joosten 2001).

1.3 Risks and threats of Ukrainian peatlands

There are many threats to natural mires and drained peatlands in Ukraine, the main ones being (modified by Movchan et al. 2017):

- Peat extraction and subsequent "recultivation" (i.e. forestry or agriculture under drained conditions);
- Amber mining: Amber is mined from mineral soils below the peat layer, and whole peatlands are left destroyed;
- Drainage for intensive agriculture (including ploughing and intensive fertilisation) or forestry;
- Drainage and subsequent abandonment, often leaving bare, nutrient-rich "black deserts" (particularly typical of small peatlands in the steppe zone in Dnipropetrovska, Donetsk, Kirovohradska, Luhansk, Mykolaiv, Kharkiv, Kherson, and Odesa Oblasts), with the spread of willows (Salix) in some areas;
- Flooding of peatlands to create reservoirs or fishponds;
- Radioactive pollution from the Chornobyl accident (especially in Zhytomyr Oblast);
- Construction of roads (particularly after 1985) or settlements and other infrastructure;
- River deepening and flood prevention (particularly in Prypiat and Stokhid River floodplains);
- Privatisation and sale of land. By 2011, 80% of drained peatlands used for agriculture were owned by individuals and local governments, with usually small (2–3 ha) land plots, hampering restoration efforts;

1 suckler cows are beef cows whose calves are kept with cows for natural fattening for up to 6-8 months. Accordingly, the term "suckler herd" means a herd of suckler cows

- Organic and inorganic pollution, for example as a result of intensive peat mineralization, the use of fertilizers and plant protection products.

The artificial water regimes of drained peatlands are often poorly managed and this has led to an increased exchange of ground and surface waters and to water pollution (including radioactive pollution). In Ukraine this is a serious problem as there is a lack of good quality drinking water in most regions.

To summarise, it can be said that drained peatlands do not perform the functions to which they are entitled in the landscape balance (see clause 2.3.1 for details), and the corresponding ecosystem services are not provided. The solution to tackle these problems and restore peatland ecosystem services is to rewet the peatlands and, if necessary, switch to paludiculture.

1.4 Peatland rewetting

It is recognised that peatland rewetting is an effective means of restoring peatland functions and reducing greenhouse gas emissions (Leifeld and Menichetti 2018; Zhong et al. 2020).

In the past, nature conservation goals were mostly decisive. Recently, drained peatlands have been increasingly rewetted in order to reduce greenhouse gas emissions. However, it is recognised that rewetting does not achieve nature conservation goals (Remm et al. 2019), but instead creates entirely new wetland ecosystems (Kreyling et al. 2021).

In Ukraine, here and there uncontrolled and random rewetting took place, initiated by beavers in abandoned peatland areas (Chornobyl buffer zone) or due to neglecting the maintenance of the amelioration systems (Photo 1). There are also cases of targeted practical measures aimed to restore and water peatlands for environmental protection purposes or to mitigate the effects of climate change, such as restoration of Zalyvky bog (Roztochchia Biosphere Reserve, Lviv Oblast) and Chorne Bagno bog (Zacharovanyi Krai National Nature Park, Zakarpattia Oblast).

There is increasing evidence of the role of peatlands as carbon reservoirs and as a source of greenhouse gas emissions and nutrient runoff. It is important to protect the carbon reservoir and reduce emissions to a minimum. This can only be achieved by rewetting drained peatlands (Tanneberger et al. 2000).

If the peatlands are rewetted, there are two options for their further development: the peatlands can be left without further human intervention, and after adaptation to new hydrological conditions, an increase in biodiversity in this area can be expected. But peatlands can continue to be used with management methods adapted to the new situation, namely: harvesting plants that develop as a result of succession after rewetting (wet meadow or wet pasture paludiculture) or growing targeted vegetation that is suitable for the respective location (cultivated paludiculture), such as reeds, cattails, sphagnum moss or alder (Wichtmann and Wichmann 2011; Tanneberger et al. 2021).

The most important ecosystem services (ESs) to be obtained after rewetting, which are also easily quantifiable, are the production of biomass and the reduction of greenhouse gas emissions. Emission reductions through rewetting could be confirmed by means of a label or certificate using an approach for calculations in which greenhouse gas emissions are determined through vegetation characteristics (GEST approach). Other ESs could perhaps also be marketed as part of various initiatives. Rewetting and paludiculture can, for example, also be associated with a regional cooling effect, nutrient and water retention, biodiversity enhancement, conservation value and historical value of natural peatlands as "live nature archives". Other benefits include the emergence of local products on the market (which reduces the distance between the producer and the consumer), materials and products that store absorbed carbon (for example, building materials), and the replacement of non-renewable energy sources.

Depending on land use type and drainage intensity under initial drained conditions, between 17.25 (shallow drained grassland) and 38.18 t CO_2 equivalents per ha per year (cropland) are emitted on average in temperate latitudes. In tropical climate, cropland emissions can reach up to 58.45 t CO_2 equivalents per ha per year ((Tanneberger et al. 2020) according to IPCC 2014 data).

The basic principle is to raise water tables of drained organic soils (peat soils) up to the height of the soil surface (soil moisture class 4+, 5+, 6+; see Table 1), whereby the peat body is permanently preserved. The greenhouse gas emissions and other substance emissions from the drained peat body are minimised or, ideally, stopped.

It may even be possible to achieve renewed peat formation and, accordingly, sequestration of carbon and nutrients. For this purpose, average peat-preserving water levels should be maintained in summer and winter (soil moisture classes 4+, 5+ and 6+; (see Table 1)). The water table level should be corresponding to soil moisture classes 4+, 5+ or 6+ for the majority of the area. The larger the rewetted portion of the total area is, the larger avoided greenhouse gas emissions will be.

Table 1
Soil moisture classes relevant for rewetting (4+/5+/6+) (Jurasinski et al. 2016)

Soil moisture class	Median groundwater table (cm from soil surface)	
	Winter/spring	Summer/autumn
2+	-35 — -70	-45 — -85
3+	-15 — -35	-20 — -45
4+	-5 — -15	-10 — -20
5+	+10 — -5	0 — -10
6+	+150 — +10	+140 — 0

In general, peat-preserving or even peat-forming management is generally no longer possible at water level 4+. In this way, only peat depletion-reducing conditions are achieved. Exceptions are alder swamps (Schäfer and Joosten 2005) or coastal flooded peatlands, where the boundary between moist and wet salt grassland stands is between 13 cm and 24 cm from the soil surface (Seiberling 2003).

1.5 Ukraine's international obligations regarding peatland restoration

Ukraine has a number of international obligations related to the conservation, protection and restoration of peatlands. These obligations reflect the multiple roles that peatlands play in the well-being of our planet and its biosphere.

First of all, it is worth mentioning the Paris Agreement, which Ukraine ratified by Law No. 1469-VIII of 14.07.2016. The Paris Agreement emphasizes the importance of peatlands for the climate as carbon sinks. This involves the secondary moistening of 500,000 km^2 (50,000,000 hectares) of drained peatlands worldwide by 2050-2070, as well as “taking measures to preserve and increase, where appropriate, sinks and reservoirs of greenhouse gases...” This means that further drainage of peatlands and peat extraction in Ukraine contradict the commitments made.

Since 2020, countries have been submitting their national climate action plans, known as Nationally Determined Contributions (NDCs). Each subsequent NDC must reflect an increasing level of ambition compared to the previous version.

In their NBC reports, countries report on the actions they will take to reduce greenhouse gas emissions to meet the goals of the Paris Agreement. Countries also report on the actions they will take to increase resilience to the effects of climate change. For example, the EU plans to reduce greenhouse gas emissions by 55% by 2030 compared to 1990 levels.

On its path to EU membership, Ukraine will soon have to adapt its laws and other by-laws on environmental protection to the relevant EU Directives and Regulations.

Peatlands as part of river basins fall under the EU Water Framework Directive (2000/60/EC) (WFD), which focuses on ensuring good qualitative and quantitative status of waters, i.e. on reducing and eliminating pollution and ensuring sufficient water to support wildlife while meeting human needs. The main objectives of the WFD are to establish River Basin Management Plans and Programmes of Measures to protect and, where necessary, restore water bodies to achieve good status and prevent deterioration. Member States of the European Union have committed to achieving good qualitative and quantitative status of all water bodies by 2027.

The Verkhovna Rada of Ukraine, in order to approximate national legislation to the WFD, adopted relevant amendments to the Water Code of Ukraine on 4 October 2014. It is expected that the river basin management plans in Ukraine will be completed during 2024, and their public discussion is currently ongoing.

Unfortunately, peatlands have not received sufficient attention in the WFD. However, as peatlands play an important role in the landscape water balance and can act as diffuse sources of nutrients (if drained) or as sinks (if wet), the DESIRE project, implemented by the Greifswald Mire Centre, called for addressing peatland issues and including them in river basin management plans. Relevant proposals have been drawn up (Reference).

The Convention on Wetlands of International Importance, Especially as Waterfowl Habitat (Ramsar Convention and Bern Convention on the Conservation of European Wild Fauna and Flora and Natural Habitats) are implemented in the EU countries through Directive No. 92/43/EC on the Conservation of Natural Habitats and of Species of Wild Fauna and Flora (hereinafter referred to as the Habitats Directive), Directive No. 2009/147/EC on the Conservation of Wild Birds (hereinafter referred to as the Birds Directive).

The Habitats Directive requires national governments to designate areas that will ensure the conservation of flora and fauna species. This has led to the creation of networks of protected areas across the EU, together with "special areas of conservation", which together with existing protected areas have become the Natura 2000 network, designed to protect species and habitats. Article 1 of the Habitats Directive requires EU Member States to take "a series of measures necessary to maintain or restore natural habitats and populations of wild fauna and flora species".

In accordance with the Habitats Directive, the Emerald Network has been created in Ukraine, which includes most of the virgin peat mires, but so far, the Emerald Network has not been officially approved and, accordingly, is not protected by law, although state organizations sometimes take into account the territory's belonging to the Emerald Network when making decisions.

At the same time, Ukraine, having signed the Association Agreement with the European Union, the European Atomic Energy Community and their Member States, undertook to implement the EU Birds and Habitats Directives into Ukrainian legislation (Annex XXX to the Agreement). The draft law aimed at implementing these European Directives was developed and registered in the Parliament under number 4461 dated 04.12.2020.

The EU Biodiversity Strategy for 2030 commits to legislative protection of at least 30% of the territory, including inland waters, and 30% of the seas in the European Union, of which at least a third must be under strict protection, including all primary forests.

On 17 June 2024, the EU Environment Council adopted the Nature Restoration Law. It combines the overall objective of long-term restoration of nature on EU's land and in the seas with binding restoration targets for specific habitats and species. These measures should cover at least 20% of the EU's land and sea areas by 2030 and all ecosystems in need of restoration by 2050. The document mentions paludiculture as one example of desirable restoration measures.

In particular, the new Law states that for organic agricultural soils that are drained peatlands, Member States must introduce restoration measures:

- 30% of such areas by 2030, of which at least a quarter shall be rewetted;
- 50% of such areas by 2040, of which at least a half shall be rewetted;
- 70% of such areas by 2050, of which at least a half shall be rewetted.

As defined in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, restoration and rewetting of organic soils in agricultural use helps to achieve significant biodiversity benefits, significant greenhouse gas emission reductions and other environmental benefits, while contributing to increased diversity of agro-landscapes. Member States can choose from a wide range of measures to restore drained peatlands under agricultural use, ranging from the conversion of arable land to permanent pasture and production extensification measures accompanied by reduced drainage, to full secondary humidification using paludiculture practices or the creation of conditions for the restoration of peat-forming vegetation. The most significant climate benefits are achieved through the restoration and secondary humidification of arable land followed by the restoration of pastures.

The list of habitat types in Annex I of the Nature Restoration Law is worth mentioning separately. Member States must ensure that the condition of the area with habitat types listed in Annex I does not deteriorate. Among other habitat types, Annex I contains the types of bogs found in Northern Ukraine: raised bogs (north of Rivne and Zhytomyr Oblasts), degraded raised bogs (north of Rivne and Zhytomyr Oblasts) capable of natural regeneration, transitional bogs and fens (Cheremske bog of Volyn Oblast, Koza-Berezynske bog, Perebrody, Syra Pohonia, Somyne and other bogs of Rivne and Zhytomyr Oblasts), limestone bogs with Cladium mariscus and Caricion davallianae species (areas of Shatsk National Nature Park), alkaline bogs (Volyn Oblast). These habitat types should be prioritized for conservation and protection in Ukraine.

According to Parliament's position, EU countries must give priority to Natura 2000 sites (the Emerald Network for Ukraine) by 2030. Once a site has been determined to be in good condition, EU countries must ensure that its condition does not deteriorate significantly. Member States must also adopt national recovery plans, which detail how they intend to achieve the targets. The law requires EU Member States to develop national recovery plans, which set out the recovery measures needed to achieve the established goals.

2. PALUDICULTURE – CLIMATE SMART LAND USE ON PEATLAND

2.1 Brief introduction to paludiculture

The first comprehensive overview on wise use of peatlands had been published by Joosten and Clarke (Joosten and Clarke 2002). Conventional peatland utilisation requires drainage, which results in enormous emissions of greenhouse gases and nutrients and loss in biodiversity. Almost 25% of worldwide carbon dioxide (CO_2) emissions from the LULUCF (Land use, land-use change, and forestry) sector are caused by drained peatlands. Peatland degradation is also responsible for ongoing land subsidence, with annual height losses of 1–2 cm in the temperate climate.

Rewetting of drained peatlands is essential to reduce emissions and peat degradation, but rewetting has hitherto resulted in the loss of productive land, i.e. the cessation of its use. A new land use concept, called paludiculture ("palus" is Latin for "swamp"), combines production, soil quality conservation and, sometimes, the restoration of peat formation processes (Wichtmann et al. 2016). The main principles of paludiculture are given below.

Paludiculture is the agricultural or silvicultural use of wet and rewetted peatlands. Paludiculture uses spontaneously grown or cultivated biomass from wet peatlands under conditions where the peat no longer decomposes or even starts to "grow". It differs fundamentally from drainage-based conventional peatland use, where drainage leads to peat decomposition and, as a result, greenhouse gas emissions and nutrient leaching, and ultimately to the destruction of the production base through peat soil degradation.

Paludiculture can be described as productive land use of wet peatlands that stops soil subsidence and peat depletion and minimizes emissions and leaching of peat decomposition products. In contrast to agriculture, which is based on the drainage of peat mires, paludiculture uses plants that are adapted to high water tables, such as reeds, cattails, sedges, alders, mint, etc. An overview of potential plants for paludiculture is given in the Database of Potential Paludiculture Plants (DPPP), which is developed and updated by the Greifswald Mire Centre.

To date, there is no information on the implementation of paludiculture on rewetted peatlands in Ukraine. However, there are several traditional land uses on wet peatlands and mires, such as harvesting common reed (Phragmites australis), picking berries, etc., on natural and semi-natural areas and haymaking on wet meadows, which can be regarded as paludiculture (see Section 1.2.1).

From a business perspective and neglecting external costs, wet management is associated with higher costs than drainage-based peatland management. Pioneers of paludiculture in particular may face disadvantages compared to drainage-based peatland management. The sites show low carrying capacity, which requires soil-friendly cultivation and harvesting techniques that do not destroy the soil. Accordingly, investments must be made in site-adapted technology. This requires the use of specialised machinery with adapted undercarriage, which usually has a lower impact force than the machinery used on drained peat grassland (Wenzel et al. 2022).

If the rewetted peatlands are to be managed using animal-based methods, only animal species that can cope with the wet conditions on the land (e.g. water buffalo, geese, ducks) and that can utilise the comparatively low-quality biomass can be considered (Närmann et al. 2021). Here, too, additional costs are to be expected, e.g. through the construction of species-appropriate stables, fencing systems, the establishment of new herds, etc.

One problem is that dominant stands can produce higher yields and higher quality crops if the water table is set lower than is necessary to optimally protect the peatlands and reduce greenhouse gas emissions. Or the groundwater table may decline again over time, meaning that the ecosystem service of "climate change mitigation" is no longer provided or is only partially provided. Another challenge may be the traditional use of "drained" peatlands next to paludiculture ones in the same area. However, this is being addressed by a monitoring program that regularly checks whether the groundwater level in paludiculture sites is optimal.

2.2 Land use opportunities on rewetted peat soils

A wide range of alternative wet land use options can be presented for European peatlands (see chapter 3). To respond to the globally increasing competition for land, to maintain the production function for rural livelihoods and to retain and restore wet grasslands as hotspots for biodiversity, a simple cessation of land use is no option in many peatlands. As a consequence, a fundamental transition to "wet" land use, respectively paludiculture, is inevitable ((Tanneberger et al. 2021).

Figure 2 shows that greenhouse gas emissions on peatlands are strongly corresponding to medium water tables. The range of greenhouse gas emissions from drained peatlands (conventional use; medium water tables between -40 cm and -120 cm) is from about 20 tonnes CO_2 equivalents per hectare per year up to more than 50 tonnes CO_2 equivalents per hectare per year.

When secondary wetting of the peatland, which leads to a rise in the medium water tables between -15 cm and +5 cm, emissions are reduced to minimal methane values. The gas is released to the surface mainly in shallow, inundated peatlands. This can be partly mitigated by local vegetation that develops on the rewetted areas. Ultimately, by rewetting peatlands, we can achieve a reduction in CO_2 equivalent emissions of 10 to 40 tonnes per hectare per year (see Figure 2).

Referring to avoiding CO_2 emissions, this kind of carbon farming[2] involves practices that improve the rate at which CO_2 is removed from the atmosphere and converted to plant material and/or soil organic matter. Carbon farming is successful when carbon gains resulting from enhanced land management and/or conservation practices exceed carbon losses. New funding options are based on this, for example, "carbon credits" (see section 6. Greenhouse Gas Emissions). Carbon farming includes peatland restoration and most paludiculture methods. In other words, carbon farming on organic soils is, if combined with productive use of the plant biomass, can be considered paludiculture (Tanneberger et al. 2021).

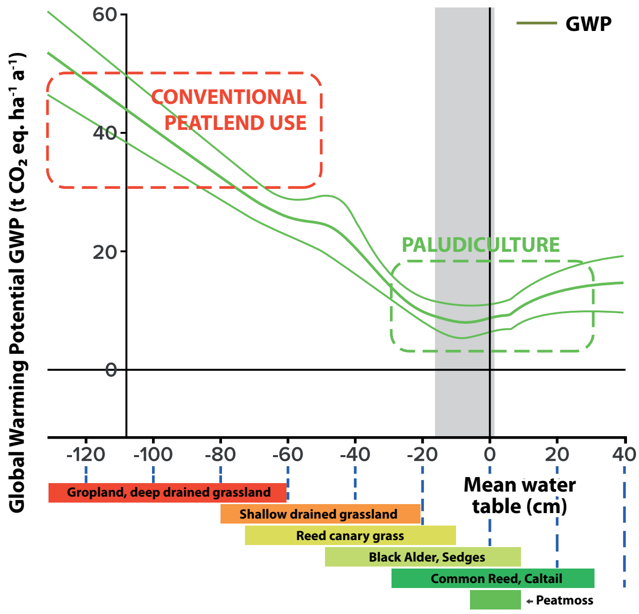


Figure 2.

Results of a meta-analysis of greenhouse gas fluxes (CO_2, CH_4) in temperate peatlands and mean water table with typical water table ranges of conventional land use and paludiculture (grey column). This Figure is constantly updated as new data become available (Gaudig and Tanneberger 2019; Couwenberg et al. 2011). Recent flux measurement results are continuously integrated into the Greifswald Mire Centre's (GMC's) emission database[3]. Latest analyses show that emissions of drained peatland are even higher.

The diverse options for value adding manufacturing of biomass from paludiculture shows that the

2 Carbon farming is a new way of farming based on the principle of reducing the carbon content in the soil. In this way, carbon emissions are not released into the atmosphere, thereby reducing the impact on climate change. Carbon farming can apply solutions such as: using fertilizers with a high carbon content, reducing or eliminating tillage, planting cover crops to change the farming ecosystem, and others.

3 https://greifswaldmoor.de/home.html

paludiculture system has great potential for the bioeconomy (Wichtmann and Peters 2022; European Commission 2018).

The European Commission has set five main objectives for the bioeconomy (European Commission, 2018), namely:

- ensuring food and nutrition security;
- managing natural resources sustainably;
- reducing dependence on non-renewable, unsustainable resources whether sourced domestically or from abroad;
- mitigating and adapting to climate change;
- strengthening European competitiveness and creating jobs.

All of these objectives are largely or completely addressed by paludiculture, except for the first objective of ensuring food and nutrition security. However, it should be noted that some food products can be produced by paludiculture methods (meat, milk, berries), perhaps to a lesser extent than on drained peatlands, but with clear environmental advantages compared to drainage-based peatland management (Wichtmann et al. 2016b). On the other hand, the focus on paludiculture can reduce the pressure on mineral soils caused by the cultivation of energy crops by gradually abandoning the cultivation of energy crops on mineral soils and using these soils for food production.

The necessity of peatland rewetting is to be integrated also into other land-based climate protection measures— with such an integrated approach, measures in different sectors complement rather than hinder each other. For instance, the planning and the construction of wind power or solar energy plants on drained peatlands has to be combined with rewetting or at least a commitment to later rewetting of the peatland must be made.

2.3 Peatlands, nutrients, and carbon

Water saturated peatlands act as sinks for nutrients, pollutants and carbon in the landscape. When peatlands are drained for agricultural or forestry use or for peat extraction, they are transformed from a sink into a source. As a result, nutrients contained in soils (nitrates and phosphorus) are released and pollute aquatic ecosystems, and greenhouse gases (GHGs) that affect the climate are emitted into the atmosphere. This means that all degraded peatlands in Ukraine contribute to climate change, eutrophication of rivers and, as a result, pollution of the Black and Baltic Seas.

In addition to greenhouse gas emissions and nutrient leaching from drained peatlands, water bodies are also damaged. Drainage of peatlands causes nutrient losses through runoff with infiltration and drainage waters. At the same time, large amounts of nitrogen, water-soluble organic compounds, potassium and phosphorus applied with fertilizers enter surface waters. This means that drainage and intensive large-scale agricultural use of peatlands leads to disruption of important ecological functions and negative external effects that can spread far beyond the peatland area. Mineralization of drained organic soils and excessive use of fertilizers lead to nutrient pollution of adjacent surface waters (rivers, lakes), groundwater and seas. Consequently, surface waters suffer from cyanobacterial blooming, micro– and macroalgae accumulate there, which causes oxygen deficiency. As a result, the quality of the habitat for fish and other aquatic organisms deteriorates, which negatively affects the biodiversity of surface waters, as well as the fishing industry, the tourism industry and, thus, the local population.

2.3.1 Effects of rewetting on nutrient balance

Natural and successfully restored peatlands act as the “kidneys of landscapes”, filtering nutrients from groundwater and surface waters flowing through them. Wet and rewetted peatlands can retain nutrients from their feeding waters and natural deposits. In waterlogged soil conditions, these nutrients are absorbed by vegetation, eliminated (as nitrates, which evaporate after denitrification in their redox forms – NO_2, NO, N_2O, N_2, NH_4) or precipitated (as phosphorus), and in the long term – sequestered by the transformation of plant biomass into newly formed peat (Vroom et al. 2018). The removal of nutrients by harvesting paludi-biomass from rewetted peatlands has additional positive effects on freshwater protection (Geurts et al. 2020). Studies of biomass harvesting in lowland peatlands (peatlands fed by groundwater and surface water) in the Netherlands have shown nitrogen retention efficiencies of up to 93-99% in the soil, which will prevent emissions and leaching (Wassen and Olde Venterink 2006).

Peatlands can also accumulate nutrients and carbon by converting plant biomass into peat under waterlogged soil conditions. In addition to reducing greenhouse gas emissions through rewetting, the conversion to paludiculture has other positive climate effects:

a) carbon fixation effect in the finished product (for durable products such as construction and insulation materials, furniture, etc.);
b) fossil fuel substitution.

Drainage and agricultural use of peatlands leads to soil degradation and destruction (deterioration of quality, mineralization, compaction, subsidence, erosion, desertification), greenhouse gas emissions and water pollution through the release of nutrients. Peatlands can also be degraded by other external causes, such as pollution and nutrient enrichment (e.g. sedimentation, runoff of agrochemicals from agricultural fields into adjacent water catchments). The latter is evident in the case of pollution or nutrient enrichment of surface water or groundwater.

There are several biogeochemical processes associated with peatland rewetting and their conversion to paludiculture that can affect the nutrient retention capacity of peatlands and their potential solubility. Various studies show that the physical properties of the most disturbed near-surface peat soils do not correspond to reference conditions close to natural peatlands, even several decades after restoration, although the natural water table has been restored (Kreyling et al. 2021). Although restoration methods have improved in recent years, the process of restoring natural hydrological conditions is still a complex and time-consuming process. Studies by some authors (Land et al. 2016; Zak et al. 2014; Walton et al. 2020) have shown that the most serious problem for water resources protection may be increased phosphorus leaching from rewetted sites which were drained and fertilized in the past and have an unfavourable iron-phosphorus ratio.

Secondary rewetting can have various effects on biogeochemical processes. During rewetting, all pores of the peat soil are filled with water, air is displaced, and oxygen is absent or present only to a small extent. Strong changes occur in the redox system. This improves the conditions for nitrate denitrification, ammonia dissolves, and phosphorus compounds, which were previously considered very stable, can go into solution (Lundin et al. 2017). Such a change from oxidative to anoxic conditions, on the one hand, can ensure the reduction of +/– 100% of nitrate nitrogen to N_2 without causing harm. On the other hand, this can lead to the reductive dissolution of iron (III) compounds and, as a result, to the release of phosphates. This is especially relevant for pastures where fertilizers have been used and arable lands on peat, which have been enriched – under drained conditions – with insoluble phosphate complexes. This process can lead to high concentrations of phosphorus in capillary water and become extensive if the iron to phosphorus ratio in the topsoil layer of the peatland to be rewetted is less than 10 (Jablonska et al. 2020). Dissolved phosphorus can be (partially) absorbed by vegetation and transported with harvest biomass from the site, but it can also be discharged with the water, especially in flowing (respectively, seeping) irrigated peatlands, which can contribute to the pollution of water bodies. This means that there is a risk that phosphorus accumulated in peat soils will be released downstream (Audet et al. 2020)[4].

The availability of hydrological conditions adapted to peatland conditions is crucial for achieving the objectives of protecting peat soils and reducing nutrient losses. It is quite difficult to restore natural hydrological conditions in peatlands that have undergone significant changes since drainage and have therefore lost their original vegetation and the natural structural features of the peat layers on the surface. Such peatlands were often naturally nutrient-rich areas with abundant water flow. Hydrological conditions can be restored in the long term, provided that peat-forming plant species are used (Rehell and Laitinen 2014). To improve nutrient retention, it is necessary to consider water levels, water dynamics and water quality in the peatland itself and in the catchment (Sallantaus 2014).

Although methods for restoring ecosystem functions in drained peatlands are still limited and

4 During the preparation of the publication, we received information from Ukrainian specialists that the phosphorus content in Ukrainian Polissia peat soils is low and the compounds are poorly mobile. Phosphorus fertilizers were applied in small doses – no more than 45 kg per P2O5. Vivianitic peatlands do exist, but they are widespread in local areas and will not cause any special environmental damage under the conditions of paludiculture.

largely untested (Klimkowska et al. 2019), initial recommendations can be made. If the peatland has been poorly drained in recent years and its hydraulic properties have not undergone irreversible changes, restoration measures may be limited to the cessation of drainage infrastructure operation (Pfadenhauer and Grootjans 1999; Menberu et al. 2018). Peatlands with significant hydraulic changes and long-term drainage are characterized by a decrease in the porosity, hydraulic conductivity and absorption capacity of the peat. The associated changes in the hydraulic properties of the peat are irreversible (Carroll et al. 2011; Chimmer et al. 2017). These devastated peatlands often have poor hydraulic properties. This means that their hydraulic conductivity is extremely low, they can only be rehydrated by long-term full inundation, and then new wetland ecosystems will begin to develop on them.

Given the limited scientific evidence, it is difficult to quantify the ecosystem function in terms of nutrient retention in advance. The improvement in nutrient retention due to a particular restoration measure can only be quantified once all the effects are understood. It should be noted that in the short term, nutrients may be washed out from restored peatlands, but in the long term, after restoration, the quality of runoff from peatlands improves. If the goal is to restore hydrological processes similar to natural conditions in the peatland, then active measures are needed. Apart from doing nothing, there are two main options for restoring the ecosystem function of nutrient retention:

- remove the extremely nutrient-rich top layer before rewetting (Zak et al. 2016)
- remove nutrients by harvesting the biomass after rewetting (paludiculture).

The first option is practised in terms of area for nature conservation reasons in small-scale restoration of sensitive plant communities. Since extremely large amounts of soil must be moved and this causes very high costs, this option does not appear to be effective as a measure for nutrient retention.

The amount of nutrients that enter groundwater and surface water from peatlands is determined by several factors. This depends, for example, on the type of peatland, the intensity of drainage and the type of land use. Since most of the peatlands of Polissia are lowland mires, a significant part of the peatlands used in agriculture are rich in nutrients.

The highest rates of nutrient runoff are to be expected if the peatland has been used for arable farming, as heavy machinery can only pass through at low water levels, the soil lacks a "supporting" sward, and fertilizer application is higher than in meadows. For semi-natural pastures and meadows, a smaller but still significant nutrient loss is expected. Therefore, rewetting deeply drained peat soils and conversion to nutrient-skimming paludiculture is the most effective solution for nutrient retention.

From the point of view of water protection policy, it should be taken into account that not only agricultural use based on drainage is associated with the influx of nutrients into the surrounding aquatic ecosystems, but also the abandonment of agricultural use. For transition from the drainage use of peatlands to paludiculture with its contribution to the retention of nutrients in river catchments, the issue of agricultural use of peatlands is also considered from an economic point of view.

3. PRODUCTIVITY, SUITABILITY OF LAND AND PLANT SPECIES FOR PALUDICULTURE

3.1 General overview of the paludiculture sectors

Paludiculture can be understood as a concept (Wichtmann et al. 2016b) for the restoration of degraded peatlands through rewetting combined with the economic utilisation of the biomass harvested from these areas.

Using different techniques, biomass can be processed into a variety of end products, such as insulation and construction materials, soil substrates, feed and fuel, etc. Innovative products, including medical and food, are under development. Wet peatland biomass has a wide range of potential uses: from animal feed to energy and construction materials. The management of wet peatlands provides ecological services (ESs) that cannot be provided on drained peatlands, or only to a much lesser extent. In addition to reducing greenhouse gas emissions and nutrient runoff, the area-specific biodiversity is maintained (Müller et al. in preparation).

Paludiculture pilot projects and demonstration sites on a farm scale already exist in various countries. At the same time, different directions of use of paludiculture biomass are being investigated within the framework of these projects. Markets for these products are often only in the early stages of development. A "chicken-and-egg" problem often arises (Nordt et al. 2022). Processing of paludiculture products only makes sense if there is sufficient supply of raw materials, while the supply of raw materials is only worthwhile if there are processing capacities. However, both are created only when there is sufficient demand for the final product. In terms of final products, paludiculture products must compete with close substitutes (e.g., insulation materials based on hemp or sheep wool, energy from straw or wood, beef) and with products from local wild collection and imports (e.g., roofing reeds from China or Romania) (Becker et al. 2020). Certification of paludiculture products allows for product differentiation and can facilitate further market development. Such labelling can certify production that is suitable for a particular location, draw attention to the associated ecosystem servic-

Certification of paludiculture production

Product certification is an effective means of attesting the quality that distinguishes a product from others. This also applies to paludiculture products based on ecosystem services. Currently, one of our projects is developing a certification system. The system should be suitable for application to a wide range of products made from paludiculture biomass. The certification proposals were prepared based on a literature review and the results of the work of the participants in two workshops. A paludiculture standard was developed, supported by relevant criteria, each of which can be confirmed using indicators.

The next step will be to define the methods for implementing the corresponding certificate (Wichtmann & Beckmann 2024). A list of six principles has been formulated, focusing mainly on the environmental conditions to be fulfilled and on ecosystem services.

A - Environmental component

Principle 1: Peat conservation/resource protection

Principle 2: Site adaptation

B - Safeguarding ecosystem services

Principle 3: Preservation of functions

Principle 4: Biodiversity

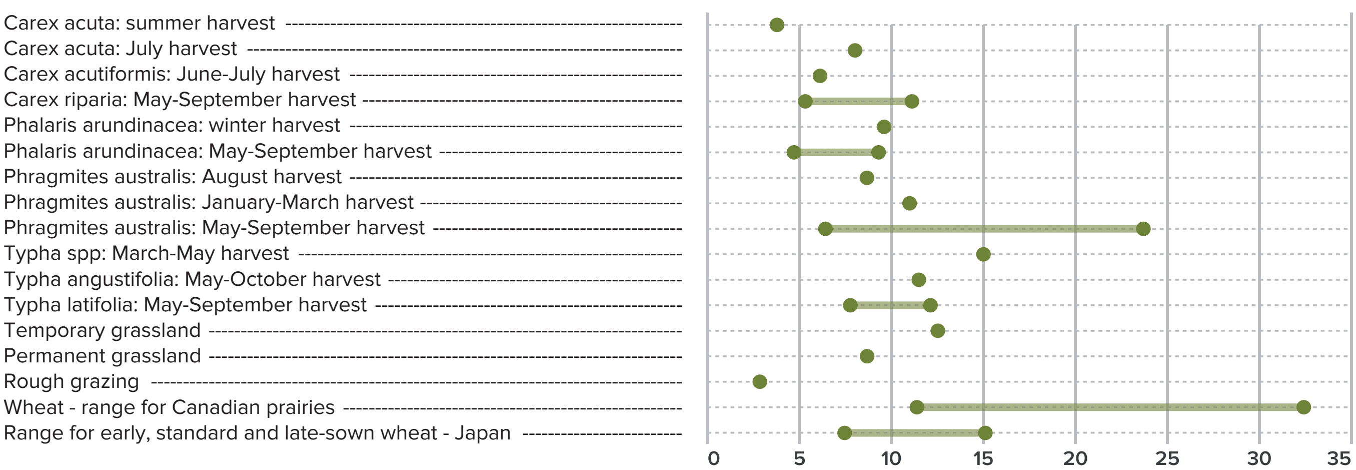
C - Legal and economic issues

Principle 5: Compliance with the law and protection of consumer and producer rights

Principle 6: Economic sustainability and sustainable development goals

Indicators are measurable and can thus confirm compliance or non-compliance with the criteria. An important indicator, for example, for principles 1 and 2 is the soil moisture class, which should be at least 4+, preferably 5+ or 6+ (see section 1.4 Peatland Rewetting: Table 1). Compliance with these and other indicators should be checked regularly (at the beginning of the project and then, for example, every 5 years) as part of monitoring or visual assessment and field surveys. It is expected that the certification system will be developed by the beginning of 2025 and the organization that will provide such a certificate will be selected. This will allow independent organizations to conduct the first audits and, if the set principles are met, producers will receive the first certificates for product labelling.

Figure 3
compares these values with reference values for some common grassland and arable crops.



es, and, if necessary, can secure higher prices for paludi products. It can also incentivise the agricultural sector to rewet and carry out wetland farming on more peatlands (Salminah et al. 2021).

Oehmke and Abel (2016) provide data on dry matter yields of various wetland plant species from "natural vegetation" or "spontaneous succession" examples.

Average annual dry-matter yields (t/ha^{-1} yr) of selected wetland plants harvested under different conditions (Oehmke and Abel 2016), compared with dry-matter yields from meadows and arable wheat fields (Mullholland et al. 2020)

Figure 3 shows that some wetland plants can match the dry matter productivity of a large part of agricultural pastures and some arable wheat fields. Although direct comparisons between arable and biomass crops can only partially provide an indication of land productivity in divergent systems, translating this natural productivity into a modern, commercially viable form of land management requires overcoming a number of challenges. These challenges, as well as the opportunities for sustaining agricultural production in areas that, if paludiculture is abandoned, may be forced to cease or significantly reduce current conventional agricultural production, will be discussed in various sections of this report.

3.2 Peatland plants potential for paludiculture

Paludiculture comprises various agricultural production systems. According to Tanneberger et al. 2021, who specified the work (Wichtmann et al. 2016b), land use options for rewetted peatlands in Europe can be conditionally divided into the following groups:

- High-intensity paludiculture: the cultivation of deliberately established, selected wetland crops under intensive management to produce the highest quantity and/or quality of target biomass. For example, the cultivation of cattail (Typha), sphagnum or sundew (Drosera);
- Low-intensity paludiculture: regular harvesting to use the biomass of spontaneously formed vegetation. For example, permanent meadow-pasture land with sedges or grasses under grazing or mowing;
- Wet wilderness: the absence of biomass harvesting and other management with the focus on the provision of regulating services and wilderness biodiversity values (e.g. rewilding).

A paludiculture pasture can be both a place for biomass collection in semi-natural areas and a spontaneously formed "permanent paludiculture pasture" after rewetting. Succession can lead to a gradual change in species composition due to increased water tables and management. Vegetation adapted to the original conditions of the site will "migrate" from the surrounding natural areas. In paludiculture farming, plants such as alder, common reed, cattail, peat moss and many other plant species can be purposefully grown (Abel, S & Kallweit, T. 2022; Abel et al. 2013) to replace existing vegetation. In areas where vegetation is protected, the replacement of natural vegetation with paludiculture crops may be limited. Environmental protection requirements must be checked and adhered to. However, it should be noted that any type of use of wet peatlands adapted to specific conditions is considered paludiculture, including, for example, berry picking or hunting. In general, it is important to consider the needs of the plants and the appropriate location of the peatland. Invasive species and their potential impact on natural habitats and native species should also be considered before introducing exotic species into paludiculture.

New approaches to the sustainable management of degraded peatlands are needed worldwide. Identification of plants for wet peatlands is essential for the implementation of paludiculture. Therefore, the Database for Potential Paludiculture Plants (DPPP) contains information on useful wetland plants that can be cultivated in paludiculture. For each entry, a “Plant Portrait” is generated, which contains information on plant characteristics and morphology, its distribution and natural habitats, cultivation and propagation methods, and utilisation options (Abel et al. 2013).

The DPPP is based on MS Access 2010. To compile the DPPP, firstly, common crops (farm plants) adapted to waterlogged conditions, e.g. cranberries, wild rice, and, secondly, typical peatland plants, e.g. sphagnum or bog moss, were collected and analysed for potential use. Plants and crops that are already successfully grown in paludiculture were also identified. The literature search included both primary (journals, books, reports, etc.) and secondary sources of information (abstracts, internet resources and other bibliographic tools). Closely related species are considered as groups with similar characteristics and potential uses, for example, Sphagnum spp., Carex spp. or Salix spp. Thus, the Database of Potential Paludiculture Plants is an overview of plants conceivable for this type of land use.

To assess the paludiculture-potential of plants, the DPPP defines four levels of suitability based on three criteria: preservation of peat soil, market potential and implementation. Preservation of peat soil is the primary concern of paludiculture. Thus, production focussing only on below ground plant parts is not eligible, since harvest would harm the peat soil. The market evaluation is based on a rough survey of internet and literature, in which the existence of a product, regardless of its quantity and quality, was taken as evidence for the presence of a market.

In addition, promising potential market demands, for example for bioenergy crops, were taken into account. Since markets for bioenergy crops are rapidly evolving, the search for new crops to satisfy the demand continues.

Not every species in the DPPP is suitable for paludiculture. Of 1128 species entered in the DPPP, 659 species could be assessed for their paludiculture-potential. About 300 of them have good or promising potential. Due to a lack of data, 469 species could not be assessed, especially species from tropical climates. For better results, further research and data gathering within the countries is necessary (Table 2).

Table 2:
Promising species for paludiculture production in the temperate zone in Europe, including Polissia, native to Ukraine (modified from Abel & Kallweit (2022))

Latin name	English name	Life form	Most promising uses	Used plant parts
Plants with available experience of cultivation and potential market demand for biomass				
Alnus glutinosa	Black alder Glutinous alder	Tree	Technical plant • wood • tannin plant • dye plant Medicinal plant Energy crop	Wood Bark Prunus Leaves
Carex spp.	Sedges	Perennial herbaceous plants	Technical plant • packaging and disposable tableware • panels • paper • livestock bedding Fodder plant Medicinal plant Energy crop	
Drosera rotundifolia	Roundleaf sundew	Perennial plant	Medicinal plant	Aboveground biomass
Glyceria maxima	Reed mannagrass	Perennial plant	Food plant Fodder plant Energy crop (biogas)	Aboveground biomass
Mentha aquatica	Water mint	Perennial plant	Medicinal plant Essential oil plant Spice plant	Leaves
Myrica gale	Bog myrtle	Shrub	Food plant Medicinal plant	Leaves
Phragmites australis	Common reed	Cereal	Technical plant • roofing material • insulation material • construction material • packaging and disposable tableware • paper Fodder plant Energy crop	Aboveground biomass
Phalaris arundinacea	Reed canary grass	Graminoid	Technical plant • packaging and disposable tableware • panels • livestock bedding Fodder plant Energy crop	Aboveground biomass
Salix spp.	Willow	Shrub/tree	Technical plant/crop • wood • basket weaving material • paints Tanning plant Medicinal plant Melliferous plant Fodder plant Energy crop	Aboveground biomass

Latin name	English name	Life form	Most promising uses	Used plant parts
Typha spp.	Cattail	Perennial plant	Technical plant • insulation material • filling material (seed hairs) • construction material • packaging and disposable tableware • soil substrate that replaces peat Fodder plant Medicinal plant Energy crop	Aboveground biomass
Vaccinium oxycoccus; V. macrocarpon	Cranberry	Shrub	Food plant Melliferous plant Medicinal plant	Berries Leaves
Plants with no detailed information on cultivation yet				
Acorus calamus L.	Sweet flag	Perennial plant	Essential oil plant Spice plant Medicinal plant Tanning plant	Rhizomes Leaves
Agrostis canina L.	Velvet bentgrass	Perennial plant	Fodder plant	Aboveground biomass
Alopecurus geniculatus	Water foxtail	Perennial plant	Medium quality Fodder plant	Aboveground biomass
Althaea officinalis L	Marshmallow	Non-grain grasses	Medicinal plant	Leaves
Amelanchier canadensis	Shadblow serviceberry	Tree or shrub	Technical plant • wood Food plant Medicinal plant Melliferous plant	Flowers Fruit Bark Wood
Angelica archangelica L.	Angelica	Non-grain grasses	Medicinal plant Essential oil plant Food plant Fodder plant Melliferous plant	Seeds Leaves Shoots
Aronia melanocarpa	Black chokeberry		Fruit plant Medicinal plant	Berries
Betula pubescens Ehrh.	Downy birch	Tree or shrub	Technical plant • wood Food plant Medicinal plant	Wood Sap Buds Leaves
Echinochloa crus-galli (L.)	Cockspur	Cereal	Fodder plant	Aboveground biomass
Eupatorium cannabinum L.	Hemp-agrimony	Perennial plant	Medicinal plant Poisonous to livestock	Leaves
Filipendula ulmaria (L.)	Meadowsweet	Perennial plant	Tanning plant Medicinal plant Dye plant Essential oil plant Summer melliferous plant Fodder plant (silage)	Leaves Flowers
Frangula alnus Mill.	Alder buckthorn	Shrub	Medicinal plant	Bark Wood
Fraxinus excelsior L.	Common ash	Tree	Technical plant • wood Medicinal plant	Wood Leaves Bark
Glyceria maxima	Reed mannagrass	Perennial plant	Technical plant, used for roofing houses Fodder plant	Aboveground biomass
Gratiola officinalis L.	Common hedgehyssop	Non-grain grasses	Medicinal plant Tanning plant Dye plant Pollen plant	Aboveground biomass

Latin name	English name	Life form	Most promising uses	Used plant parts
Hierochloë odorata (L.)	Sweet grass	Perennial plant	Food plant	Leaves
Iris pseudacorus L.	Yellow flag	Perennial plant	Dye plant Medicinal plant	Flowers Seeds
Juncus Gerardi	Blackgrass	Perennial plant	Fodder plant	Stems Leaves
Lotus tenuis	Marsh bird's-foot trefoil	Perennial plant	Fodder plant	Aboveground biomass
Menyanthes trifoliata L.	Bog-bean	Perennial plant	Medicinal plant Melliferous plant Food plant	Leaves
Miscanthus x giganteus	Giant miscanthus	Graminoid	Energy crop	Aboveground biomass
Nasturtium officinale R. Br.	Water cress	Perennial plant	Medicinal plant Food plant Spice plant Oil plant Melliferous plant	Leaves Seeds
Oenanthe aquatica (L.) Poir.	Waterfennel	Perennial plant	Medicinal plant	Fruit
Petasites hybridus (L.)	Butterbur	Perennial plant	Medicinal plant Fodder plant Melliferous plant	Leaves
Picea abies (L.) H. Karst.	Norway spruce	Tree	Technical plant • wood Tanning plant Melliferous plant Essential oil plant Medicinal plant Fodder plant	Wood Sprouts Resin
Populus spp. L.	Poplar	Tree (or shrub)	Technical plant • wood Tanning plant Melliferous plant Medicinal plant Dye plant Energy crop	Wood Sprouts
Ledum palustre/ Rhododendron tomentosum	Wild rosemary	Shrub	Tanning plant Essential oil plant Medicinal plant	Leaves Flowers
Sanguisorba officinalis L.	Great burnet	Perennial plant	Fodder plant Insecticide Medicinal plant	Plant Leaves
Symphytum officinale L.	Comfrey	Perennial plant	Medicinal plant Fodder plant Melliferous plant	Leaves
Trifolium fragiferum L.	Strawberry clover	Perennial plant	Fodder plant Melliferous plant Medicinal plant	Aboveground biomass
Tripolium pannonicum	Sea aster	Non-grain grasses	Fodder plant Melliferous plant Medicinal plant	Leaves Stem
Vaccinium myrtillus L.	Bilberry	Shrub	Food plant Melliferous plant Medicinal plant	Berries
Vaccinium vitis-idaea L.	Lingonberry	Shrub	Food plant Melliferous plant Medicinal plant	Berries Leaves

3.3 Land suitability for paludiculture / Optimal peatland sites and productivity of paludicultures

Most important determining factors that decide whether the conversion to paludiculture for a hydrological area makes sense are:

- peatland type
- land ownership distribution
- land availability
- size and evenness of the site
- water availability
- history of utilisation
- quality of the water for rewetting

The type of peatland should correspond to the type of plant biomass that will be grown there. Rewetting of peatlands and the implementation of paludiculture is a concept that entails major changes. Therefore, both the landowner and the agricultural producer must agree with this. In order to be able to manage water resources in a standardized way, it may be necessary to combine areas belonging to different owners. Neighbouring landowners must be open to involving peatlands in the project. The larger the area occupied by plants is, the greater is the incentive and need for appropriate technology, infrastructure and market development. Thus, scale is an important factor for the introduction and development of paludiculture. Optimal for mire farming are large, reclaimed and heavily degraded lowland peatlands, which prevail in Ukraine. They have a flat topography and a relatively functioning hydraulic infrastructure. In addition, there should be sufficient water during the dry summer season. This can be verified using a water balance model using site specific data. More information can be found in section 2.3 in Mullholland et al. 2020.

4. PLANNING OF PEATLAND RESTORATION AND IMPLEMENTATION OF PALUDICULTURE

Any implementation of rewetting and paludiculture measures should be consistent with superordinate planning, such as a land-use plan or a River Basin Management Plan (RBMP) (van Hardeveld et al. 2020). A major shortcoming is that most of these plans do not take peatland use into account at all, and it is therefore important for peatland restoration to update these planning tools as soon as possible (Schäfer and Wichtmann 2023).

There are many reasons why peatlands, as well as their protection, irrigation and the introduction of paludiculture, should be considered in superordinate planning, such as the RBMP. One of them is the fact that, after restoration, the peatland is transformed from a source of nutrients to a sink, thus reducing the nutrient load on water resources (Schäfer and Wichtmann 2023).

In most cases, there is an overlap between different policy objectives, often of a synergistic nature. However, there may be conflicts of objectives between climate, biodiversity and water protection (e.g. phosphorus release after rewetting, greenhouse gas emissions from drained peatlands) that need to be taken into account when planning specific rewetting measures. The effect of water, nutrient and carbon retention is largely determined by the hydrological and hydrogeological integration of the peatland into the landscape. At the implementation stage, these objectives should be examined and coordinated within the framework of a feasibility study so that the right measures can be selected for specific areas. However, it is not only necessary to plan specific measures, but also to base these activities on an overall strategy that provides for future management and outlines possible ways to achieve the objectives, and also identifies and prioritizes measures for the protection of water resources through the sustainable use of peatlands (Schäfer and Wichtmann 2023).

Key principles for implementing the strategies can be found here: Clarke and Joosten 2002, section 5.4 Guidelines for the wise use of peatlands, pp. 125-127 (Tanneberger et al. 2020), and priority areas for rewetting of degraded peatlands by 2050 are described below.

Table 3:
Checklist of information requirements for pre-project studies for rewetting of peatlands and conversion to paludiculture (modified from Schlattmann and Rode 2019). Source: modified from Schlattmann and Rode 2019

Legal framework for rewetting and paludiculture
• Available conservation areas
• Available Legally protected biotopes
Area and habitat requirements
• Areas and types of mires
• Soil characteristics (soil class and type)
• Degree of topsoil degradation (0 - 30 cm)
• Hydrological regime
• Water regime (mean ground water table distance, rewettability)

• Partial or complete water level evaluation
• Land available for paludiculture after water level elevation
• Creation of constructed wetlands or wetland buffer zones or restoration of wetlands
• Cultivation of suitable peat-conserving wetland plants
Status-quo of current land use
• Type of agricultural use
• Size of the area in relation to the catchment area
• Water management (e.g., pipe drainage, pumping stations)
• Condition of technical facilities, age of water management facilities and need for their renewal
Technical demands for cultivation of paludiculture
• Rewetting ability (water yield and management options, peat depth)
• Water level regulation
• Logistical and infrastructural requirements (road infrastructure, plot size)
Technical requirements for the further processing of paludiculture biomass
• Demand potential
• Suitable utilisation paths
• Processing companies
• Distance to potential markets / consumers

There are several tools for selecting suitable areas for rewetting (Knieß 2007; Abel et al. 2013; Abel et al. 2011; Schulze et al. 2016). These include, for example, bottom-up decision support tools (e.g. DSS TORBOS, Clearance nutrient tool, Servi-peat: //servipeat.sggw.edu.pl/#/landingpage). The Decision Support System for Peat Conservation Management of Organic Soils (DSS TORBOS) provides advice and recommendations for specific fen sites. In addition, the impact on the peatland site in terms of peat conservation and greenhouse gas emissions, as well as the impact on biodiversity, is assessed. The recommendations, which are systematically derived according to the bottom-up approach methodology, are primarily intended for farm managers and their advisors.

Usable data sources for planning for peatland rewetting activities are:

- Digital terrain model
- Historic maps
- Geological maps, soil maps, topography maps
- Hydrological maps, amelioration plans, hydrologic and meteorological datasets
- Data on biotope types, forestry mapping, forestry management plots and management plans, nature conservation requirements, land cadastres, etc.
- Data bases on flora and fauna, surveys on species and habitat protection
- Data on infrastructure, pipeline routes, property, uses and landscape planning

The use of a decision support system can be a great help in planning rewetting measures. Decisions can then be made along a decision tree. Such a decision tree is a hierarchical series of questions to guide a decision concerning an object or a process. Each question concerns an attribute of the object or a process, and prompts an answer that affects the further path through the tree. Going through the tree, attributes with the largest information content are addressed first, followed by the next most relevant, and so on. Attributes can be expressed either on a categorical scale or a metric scale. Through its hierarchical structure and by reducing decisions to a single attribute at a time, a decision support tree allows its user to make a quick, substantiated decision (Schulze et al. 2016).

5 UTILISATION OF BIOMASS FROM PALUDICULTURE

5.1 General overview

Wet and rewetted peatlands can be used for production of food or animal fodder. Depending on the type and method of use, the impact on the peatland will vary. Some uses, such as hunting, mushroom or berry picking, have a minor impact on the peatland, as they do not require changes in the hydrological regime. All other land uses on peatlands can be distinguished according to the intensity of drainage. The intensity of drainage corresponds to the degree of peat mineralization, as assessed by aeration of organic soil, which is associated with problems such as leaching of nutrients into groundwater and greenhouse gas (GHG) emissions into the atmosphere (Zak et al. 2008). Peat-conserving land use practices on organic soils require water levels at which further mineralization stops. Even with low-intensity pasture management, this prerequisite is not met. This means that even low-intensity land-use schemes on peatlands do not guarantee their sustainable use (Wichtmann & Wichmann 2011a) if the groundwater level is not high enough. Currently, in Central Europe, approximately 14% of drained peatlands continue to be used for agriculture (Clarke and Joosten 2002).

Soft uses

An old and widespread form of peatland utilization is the gathering of plants. Especially in the boreal zone of Eurasia, a wide variety of wild edible berries and mushrooms are collected and dried for

Table 4:
Options for using biomass from peatlands

Sector	Utilisation	Plant species
Industry / Handicraft	Wickerwork	willow
	Furniture wood	black alder
	Building materials: roofing, construction, insulation, timber	common reed, cattail, black alder
	Mould-bodies: disposable tableware, flower racks	tall sedges small sedges reed canary grass common reed cattail
	Paper (cellulose), packaging materials	
	Chemical raw materials, “Phytomining”, lactic acid, lignin, coal	
Energy	Solid fuels	
	Biogas substrates	
	Liquid fuels: bio-diesel, bio-alcohol	
Agriculture	Fodder: hay, silage, pasture	
	Bedding Substrates	all grass types cattail
Other	Medicine	sundew, fever clover
	Foodstuffs	cattail

provision of food and vitamins during the winter period (Clarke and Joosten 2002).

Berries of Vaccinium species (blueberries, cranberries, lingonberries) play an important role as a food product in some regions of Ukraine. Ecological tourism and hunting of mammals and birds are also traditional uses of mires and peatlands (Tanneberger and Wichtmann 2011). All these soft land uses are associated with certain unavoidable disturbances, such as noise (hunting), waste generation, and some infrastructural changes, such as the construction of footbridges, pathways and places for recreation. The impact of these soft land uses on the territory, especially on biodiversity, depends on the intensity of their implementation.

Arable farming on peatlands

The percentage of peatlands used for arable farming is difficult to assess. Traditionally, in Central Europe, ploughing for crop cultivation has been widely used on drained peatlands. In Germany, hemp (Cannabis sativa) was the first crop grown on newly drained peatlands at the beginning of the 20th century (Tanneberger and Wichtmann 2011) because of its ability to compete with weeds. Nowadays, potatoes and even wheat can be grown on peat soils throughout Europe, both on raised bogs after the use of the upper peat layer and on lowland bogs specifically drained for agriculture. A recent development is the cultivation of maize Zea mays as a feedstock for biogas production (Wichtmann et al., 2009). All these land-use options require that the groundwater level is deeper than 35 cm from the soil surface in the spring when agricultural activities on the site begin. This often results in an average annual groundwater level >80 cm below the soil surface.

In the case of "classical", nature conservation-oriented rewetting, intensive agricultural production in these areas is abandoned in favour of biodiversity conservation and climate protection. Paludiculture on rewetted peatlands has been and is being developed in order to support the creation of products and services from plants adapted to wet soils. The purpose of paludiculture is the production of plant biomass on wet or rewetted peatlands. This leads to the receipt of a whole range of services that make the use of peatlands economically profitable. Wetland plants, such as alder, common reed, cattail, sedge and other grasses, can be used for food production only to a limited extent, but can provide renewable raw materials for the production of construction, insulation and other materials, paper, cardboard and other packaging, raw materials for bioplastics. They can also be used to produce alternative substrates for horticulture and bioenergy production.

In the case of paludiculture, rewetting does not preclude use, but there are still obstacles to the development of a market for paludiculture products (Nordt et al. 2022). New processing facilities will only be established if the raw material for processing is reliably available. In contrast, a switch to paludiculture can take several years (authorisation procedure, construction measures, establishment of the crop) before biomass is produced in sufficient quantities and of a quality suitable for the market. This means that current demand cannot be met immediately. For this reason, paludiculture should be seen as a long-term innovation task (Ziegler et al. 2021).

5.2 Harvesting and processing

5.2.1 Biomass harvesting

The harvesting process should always be in line with the anticipated use of the biomass and correspondingly adjusted to it. Some pre-processing is possible during harvesting like chopping, combing, bundling, or baling. But processing is not necessarily needed for every use. High quality biomass (for thatching or for weaving mats) and unspecific biomass (for energy use) can be distinguished.

Biomass harvesting and processing in wet peatland management faces two main challenges: the machinery should be adapted to wet sites with low carrying capacity and should have a high acreage performance. The carrying capacity of peatlands is determined by the humidity of the soil (thus the ground water level) and vegetation cover (plant species, density of the sod). According to Prochnow & Kraschinski, the trafficability of peatlands is not a technical but rather an economic problem (Prochnow and Kraschinski 2001). Very light and specially equipped machinery adapted to harvesting wet sites is available, but it is usually associated with poor performance, increased time consumption, high costs for purchasing and leasing. The carrying capacity of the plant sods decreases by repeated passing over. Additionally, for the use of light and site-adapted machinery, it may be necessary to fortify tracks or access points that are frequently used to avoid structural damages in peat soils.

There are several technical solutions for harvesting and processing of unspecific biomass on large wet peatlands. The main basic machine types are (Tanneberger and Wichtmann 2011):

- Caterpillars: tracked vehicles, available from several supplier companies, have large bearing surfaces so their weight is distributed very well over the ground, but they can cause damage to the vegetation during tight manoeuvres.
- Seigas: light vehicles with two or three axels and low pressure balloon tyres. Originally built by the Danish Seiga company, they are no longer produced by them, but now built by several small companies. They are able to float but are hard to manoeuvre which in some cases can cause damage by wheel-spin (see below).
- Machinery with reduced air pressure in the wheels, typically used in dryer grassland and humid meadow management. These machines have cutting devices which are mounted on the front of the machine and any transport facilities constructed on the rear or on a trailer. The cutting device can be arranged in different ways, according to the anticipated utilization of the biomass. It can be a sickle bar mower or a horizontal or vertical rotating mower, possibly combined with a shredder. Harvested biomass with stem lengths of 1–15 cm can be taken for most uses in the industry and handicraft sector as well as for energy purposes.

Depending on the needs in storage and further manufacturing, biomass harvesting can follow several approaches. During the harvesting process, the biomass can be baled, chopped, or bundled (see Figure 4).

Depending on the water table, the biomass can be temporarily deposited on the ground and harvested in one, two or three working steps. Wheel-based special technology with low-pressure balloon tyres has been established in reed mowing in Europe for decades. These relatively light, three–to six-wheeled vehicles from the Danish company Seiga have a device for cutting, binding and tying reeds. However, at high water levels they can float up. They are then difficult to manoeuvre or can cause damage to the sward (Dahms et al. 2017). However, large numbers of similar machines are used in Ukraine to cut reeds for roofing, e.g. in the Danube delta.

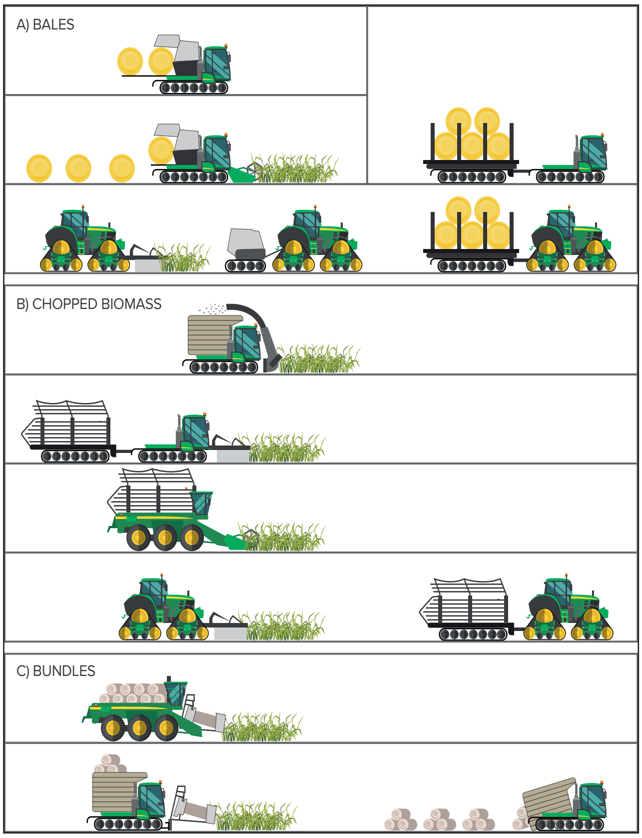


Figure 4.
Alternatives for harvesting biomass from paludiculture sites.

Photo 7.
Seiga-like reed harvesting machines waiting for the next harvesting season near Vylkove, Odesa Oblast, Ukraine (Wichtmann 2017)

Photo 8.
Seiga-like replica in Reni, Odesa Oblast, Ukraine (Haberl 2017)

Track-based technology generally involves individual solutions based on converted snow groomers from European ski resorts. The wide tracks result in low ground pressure (50-100 g/cm^2) despite a relatively heavy machine. However, they can also lead to damage to the ground if they are operated incorrectly or if same locations are driven over too often (Dahms et al. 2017).

5.2.2 Compaction and storage

The biomass has to be transported from the edge of the field to the farm or the place of further processing using conventional agricultural technology, i.e. with tractor and trailer combinations or bale transport wagons. Loose biomass can be transported with lorries (e.g. two-axle tractor, tractor unit with a three-axle rear tipper trailer, tipper as a semi-trailer), as this transport technology has a larger loading capacity of up to 100 m^3 or 24 tonnes. However, this technology generally requires the commissioning of contractors and is acceptable for long transport routes (Dahms et al. 2017).

Demand for preparation and storage of biomass from paludiculture should be oriented at the type of utilisation and transport distance. The whole utilisation chain should be adapted to the requirements of further processing and e.g. the following options are available (see Photos 9 – 14):

- Loose hay can be taken up by a loading trailer and transported to a nearby storage, e.g. a barn. Chopping the biomass reduces the volume considerably. The hay can be used as fodder or bedding material for cows, sheep and other livestock or for local heat supply by burning.
- Bundles are the means of choice e.g. for reed for roofing, as the harvesting machine already prepares pre-bundles which are manufactured to final tradeable bundles. These in turn are usually grouped together in large bundles for transporting to a construction site.
- Round or square bales are less sensitive to transport distance than hay, as they are compressed. They can be used in the agricultural sector but also for many other uses
- Pellets or briquets
- Silage

The performance or the effort required to remove the biomass from the harvesting site is determined by the stability of the sward, the current groundwater level and the performance of the machinery used.

Photos 9-10:
Different ways to prepare biomass from paludiculture for transport and further processing (from top to bottom: hay, bundles of reed (Wichtmann))

5.3 Scaling

A major challenge is the continuous provision of biomass for further processing throughout the year. To achieve this, the harvested crop must be preserved, i.e. made suitable for storage. This is possible, for example, by drying it into hay and making it available in the form of round bales. Drying the soil after mowing can be difficult in wet years when groundwater levels are high. Alternatively, the fresh biomass can be preserved as silage, whereby soil drying can be avoided. Silage can be stored in a mobile silo or tube silo, for example. So far, however, there is only experience with the use of silage for the production of construction panels (Gusovius et al. 2019).

It is possible to scale up the use of grass fibres in production by initially using a lower propor-

Photos 11-14:
Different ways to prepare biomass from paludiculture for transport and further processing. From left to right, from top to bottom: round bales, pellets, silage in round bales and large scale silage silo (Wichtmann)

tion of grass fibres in the end product (10 – 20%), which can be increased in the future as experience grows and potential technical adjustments are made. In the medium term, the processing capacity in the processing industry can be increased, i.e. adapted to the increasing volume of biomass from paludiculture.

Smaller paper machines produce approximately 40,000 tonnes of paper, larger machines produce up to 400,000 tonnes of paper per year. With a possible substitution share of 30% of classic wood pulp with the new grass-like fibre pulp, this results in a demand of 12,000 – 120,000 t/a. It is estimated that 1.25 tonnes of wet meadow hay are required for 1 tonne of pulp.

5.4 Paludiculture and the growing industry of soil mixtures

Peat is unrivalled for use as a growing medium. This relates firstly to its hydraulic properties, as peat has a very good water-holding capacity. In addition, its pH is acidic and there are hardly any nutrients, i.e. by liming and mixing in nutrients, such substrate can be adapted precisely to the needs of the crops to be grown.

These advantages of peat are difficult to achieve with substitute growing media. Sphagnum biomass, which is produced in paludiculture, seems to be the most suitable. Currently, the EU has implemented a certification system for substitute mixtures that confirms that peat is not used in the mixtures, but unfortunately, this certification system does not include substrates the production of which is based on biomass from paludiculture.

Efforts are being made to replace peat, which is used as a substrate in horticulture, with biomass grown in paludiculture. Several kinds of substrates and, respectively, growing media can be produced using biomass from paludiculture plants as a basis material.

An example from Canada is an initiative in Saint-Modeste, Quebec, which started in 2013 as a collaboration between researchers and the private sector (peat industry). The initiative explores the potential of sphagnum farming, i.e., the cultivation of peat moss (Sphagnum) for the production of horticultural growing media. The project is in the exploratory phase in which sphagnum farming is explored for future commercial use but is currently not a source of income. The initiative performs water level management and adapts it for optimal plant growth. Next to biomass yields, also greenhouse gas emissions are being monitored *(Ziegler et al. 2021)*.

Currently, several projects are ongoing which on one hand are dealing with the use of Sphagnum mosses, which are cultivated in rewetted bog peatlands OptiMOOS – Moorwissen en. There are also projects dealing with composts from higher plants like cattail Typha spec. *(TyphaSubstrat – Moorwissen de)*.

A collaborative research project together with the private sector (peat and growing media industry) was initiated in 2010 in the Hankhauser Moor in Lower Saxony, Germany. They focused on the production of "environmentally friendly and sustainably produced" as well as "regionally produced" fresh Sphagnum biomass as a raw material for horticultural substrates and as a starter material for bog restoration. The initiative innovated in the set-up of a system of sphagnum farming. The monitoring of environmental benefits, in particular greenhouse gases, biomass yields, and biodiversity benefits as well as the economics of Sphagnum farming were very well documented (Wichtmann et al. 2020).

5.5 Paludiculture for energy

5.5.1 General aspects on energetic utilisation

A comprehensive overview on plants which can be used for energy production can be found in the "Database of Potential Paludiculture Plants" and may be checked if they are appropriate for certain agroclimatic zones Abel, S & Kallweit, T 2022). Mullholland et al. 2020. filtered plant species according to their main uses, in particular, for energy production; this resulted in 24 plant species, including reed grass (3 species), cattail (3 species), sedge (7 species), grass (1 species), deciduous trees (6 species) and coniferous trees (4 species). All these species are natives or considered neophytes (introduced species now naturalised), and all are perennial.

5.5.2 Tall sedge (Carex spec.) and reed canary grass meadows

(modified from Birr et al. 2021)

Tall sedge meadows are dominated by productive sedge species and complemented by a variety of wetness-tolerant species. A firm sward makes the stands passable even at high water levels. Sedges prove to be tolerant to flooding and altering wetness. They can be used as forage meadows with either one or two cuts per year. Energetic utilisation of the biomass is also possible.

What locations are suitable?

Cultivated grassland on fen peatland as well as fallow land and previously arable peatland sites are suitable for the use as tall sedge meadows on the condition that the water is kept at an appropriate level. The aim is to maintain a stable water level just below the soil surface throughout the summer. In winter, every now and then slight flooding is possible. Sites with high nutrients level, such as previously intensively managed grassland, offer suitable conditions for productive wet meadows, which are mainly composed of tall sedges. In the case of rewetting of previously drained peatlands, sedges adapted to the habitats with oxygen depletion in the root zone

Water level:	(1) 10-20 cm below ground level in summer, 5-15 cm below ground level in winter (water level class 4+) or (2) 10 to 0 cm in summer, 5 to 15 cm in winter (water level class 5+)
Cultivation:	Natural establishment after water level rise or targeted through planting or seeding
Yield:	2-12 t of dry matter ha^{-1} yr^{-1} (one- to two-rotation)
Utilisation:	Energy biomass (fuel, substrate for biogas plants), fodder, bedding, packaging
Projected long-term emissions:	~10 t CO_2-eq. ha^{-1} yr^{-1} (soil moisture class 4+ under GEST approach) ~3 t CO_2-eq. ha yr^{-1} (soil moisture class 5+ under GEST approach)

Photos 15 and 16:
Left: Loose hay, mainly from sedges and reed canary grass, in rewetted Polder Seewiese near Neukalen (Mecklenburg);
Right: Onsite Compaction (baling) of sedge hay with adapted grassland technology for energy utilisation in Neukalen, Germany (Photo: Wichtmann 2017).

and at the same time high nutrient supply of the degraded peatlands, can show very high propagation rates and productivity.

In Ukraine, the Cyperaceae family, to which sedges belong, includes 148 species (Danylyk and Koopman, 2023), and is one of the most species-rich groups, which can contribute to the restoration of the peat formation process. They are characterised by a predominantly triangular stem base and corresponding three ranked standing leaves. Large sedge species such as lesser pond-sedge (Carex acutiformis), greater pond sedge (Carex riparia) or acute sedge (Carex acuta) are suitable for productive use under wet conditions with the expected high yields. Reed canary grass (Phalaris arundinacea) is more productive if the water tables are slightly lower and its very competitive, if water tables are fluctuating.

What steps are needed to restore wet meadows?

Even after 15-20 years of intensive use as grassland or arable land, seeds of the former fen vegetation can survive in the soil. By activity of soil burrowing animals, scarifying the soil, or extensive management with soil-conserving grazing, the seeds reach the light and germinate. The seeds float on wet meadows and can be dispersed on the area during flooding. In order to fully exploit the positive effects of seed dispersal in water, water management must be adjusted accordingly: overflowing ditches and interconnected ditches in the catchment are the best way to spread floating seeds to new areas. However, severe flooding during the first growth phase, in addition to increasing methane emissions, also negatively affects plant rooting. Spontaneous colonization by sedges and reed canary grass takes about three years.

It is also possible to establish the sedge stand or a canary grass dominated reed artificially, which involves a considerable financial investment. However, this is advisable in a case if the water-logged area is isolated from initial sedge stands or if the future stand needs to be used very quickly. A stand can also be purposefully established by planting pre-sown seedlings (from seed or by rhizome division). The soil should be prepared to minimise competition from companion species. As sedges have a lower vegetative spreading speed than, for example, reeds, the planting density should be at least 0.25 plants per m^2.

What needs to be considered in water management and nutrient supply?

The highest yields are achieved with low summer flooding. In winter, a flooding of 0-30 cm is tolerable by sedges, reed canary grass is pushed back in favour of sedges. In the first few years, nutrients are supplied through mobilising the nutrients of the degraded, rewetted peat. In addition, irrigation water from nutrient-polluted waters can be directed over the area, which has positive effects on biomass yields (Wenzel et al. 2022). Without nutrient replenishment, decreasing nutrient availability and an associated decline in yields are possible in the medium term.

Expected harvest quantities and harvesting conditions

Depending on the sedge species considered, yields of up to 12 t of dry matter ha^{-1} yr^{-1} are possible. Yields of less than 2 t of dry matter ha^{-1} yr^{-1} are not common even in case of decreasing nutrient availability and the associated yield reductions. More land may then be needed to maintain the needed biomass resource flow.

Harvesting of most sedge species and reed canary grass can be done once or twice between summer and late autumn. It can be carried out with adapted conventional technology (e.g. twin tyres, wide tyres with air pressure control) when water levels have dropped in summer. In the case of high-water levels, single-stage harvesting methods are used, for which special technology is required.

If the hay is used for heat generation, harvesting in late autumn are recommended, as this improves the combustion properties of the biomass. Whereas for use in biogas plants, harvesting is better done in early summer. Wet meadows must be managed with special technology adapted to the soil and moisture conditions. For general information on harvesting technology, biomass storage and infrastructure, see chapter 5.2.

What material and products utilisation options are available?

The extraction of bedding material from wet meadows is getting popular again because of its good absorbency. Like the purple peatland grass (Molinia caerulea) meadows that are widespread in southern Germany, tall sedge meadows are also used to produce litter for bedding. After use as litter, further use in the biogas plant or as organic soil component is possible. The latter is a better solution on the way to a closed nutrient cycle.

Wet meadows established from acute sedge (Carex acuta) and from reed canary grass (Phalaris arundinacea) can be a good horse feed because of the high silica and low protein content. The feed value of wet meadow growth generally decreases rapidly. It ranges between 5.4 MJ net energy content for lactation per kg of dry matter (before flowering) and 4.3 MJ net energy content for lactation per kg of dry matter (at the end of flowering). If the treading resistance is sufficient, early grazing with a fairly high stocking rate can be carried out for a limited period of time. Late post-grazing is only recommended for a short period because of the low forage value. Ensiling of wet meadow growth is only worthwhile with an early cut. Wet meadow biomass can also be directly applied as organic fertiliser on arable land or for compost production. In particular, overgrown/straw-like vegetation can be used as mulch material in fruit growing, landscaping, on road embankments, etc.

Outside the agricultural sector, sedges and sweet grasses like reed canary grass can generally be utilised for the production of cellulose as a raw material for paper and cardboard production, for fibre cast mouldings or for construction plates and many other things.

Photos 17 and 18:
Construction plates (left) and compostable disposable tableware (right) pressed from unspecific biomass from wet meadows (Wichtmann)

Traditional loam/straw construction method is currently experiencing a renaissance in ecological building. Straw-like wet meadow grass material can be used for the production of insulation boards, chip boards or fibre boards. Meadow grass insulation material is also offered as blow-in or bulk insulation.

The hydrothermal carbonisation (HTC) process is used to produce biochar or HTC charcoal. With the addition of water, pressure (10-40 bar) and at high temperature (180-250°C), moist and wet meadow biomass can be converted into biochar in several hours. Biochar can be used for thermal energy, as a soil conditioner, as a peat substitute in planting soils or in filter systems.

Which properties are necessary for the utilisation?

In most cases, the harvested crop does not possess the required properties for the direct processing into the products. That is why before the final production the biomass should go through conditioning (enrichment and achievement of the desired state). Conditioning can be done through the simple methods such as crushing, tearing, cutting, grinding and ensiling, or by combining the individual steps.

Energy and products utilisation options

If harvested in late winter, grass-type biomass can be used as a raw material for the production of fuel granules (pellets), which are then thermally utilized. Productive vegetation dominated by sedge or reed canary grass is particularly profitable. Despite higher total dust emissions, raw ash content and ash melting temperatures, wet meadow hay has good combustion properties. Calorific value of tall sedges is between 17.6-17.9 MJ per kg dry matter with an ash content of 5% dry matter (section 5.5.3).

If harvested in early summer, biomass from wet peatland meadows can be used in a biogas facility. The methane yield of sedges is 126-313 m^3 per tonne of organic dry substance. The pre-digestion of the biomass is promoted by a pre-use as bedding. The operational, economic risk is significantly lower in the case of direct combustion than in the case of utilisation as a substrate, since the energy yield is higher in the case of combustion of grass-type biomass compared to fermentation.

Challenges lie mainly in high investment costs for the adapted or special harvesting technology and in securing sales (e.g. heating plants or paper mills). Combustion facilities operated with stalk biomass have lower fuel costs than oil or gas heating systems but are only competitive with these if a high number of full load hours is achieved in the facility. Stalk-type biomass can be pelleted, which expands application and sales opportunities, but also increases supply costs. Combustion in small facilities is also possible after type testing. Pellets can also be used as bedding or in further material processing.

How must the power plants be adapted to the biomass?

An automatic ash discharge system is required at large facilities. In any case, technology adapted to grass biomass should be used, e.g. fluidised bed combustion or cigar burner combustion system [5]. Biomass from sites that vary greatly in water levels, productivity and plant composition should be tested for critical constituents (especially chlorine, potassium and sulphur).

What is the current state of implementation?

Wet meadows with sedges have been used for centuries and still can be found occasionally in Central Europe. The thermal utilisation of sedge hay, which is commercially possible today, has been taking place since 2014 at the biomass heating plant in Malchin, Germany by the Agrotherm GmbH (section 5.5.4). Here, the plants from rewetted fen are burned to supply heat to around 500 residential units and some public buildings. The use as bedding material with downstream utilisation in the biogas facility is practised, for example, by Mesecke GbR Prenzlau in Brandenburg, Germany. In Spreewald, Brandenburg, Germany (Göritzer Agrar GmbH), late-mown wet meadow biomass has been thermally utilised in a stove with a gasifier since 2016. A similar sedge cultivation project was taking place in Bavaria between 2016 and 2022.

5 A description of the technology can be found here https://www.sciencedirect.com/science/article/abs/pii/S0961953413004388

Effect on greenhouse gas emissions

Under very wet conditions, sedges are good peat producing plants. Reed canary grass does not like such high water levels and is therefore not peat forming. Tall sedge meadows emit an average of ~3 t CO_2 eq. ha^{-1} yr^{-1} at water level class 5+, and ~10 t CO_2 eq. ha^{-1} yr^{-1} at water level class 4+ (same as reed canary grass). Higher water levels are thus useful for reducing GHG emissions. For both water levels, emissions are mainly caused by CH_4, a potent but short-lived GHG. In comparison, drained farmland on peatland emits over 30 t CO_2 eq. ha^{-1} yr^{-1}.

How does management influence biodiversity?

Mowing with clearing limits the build-up of a litter layer in sedge meadows and increases the availability of light near the ground. Especially small and slow-growing plant species benefit from this, so that more heterogeneous and species-rich sedge meadows can develop. As a rule, this development is also associated with an increase in faunistic species diversity. Above all, open land species as well as light– and heat-loving species benefit. Eurasian skylark, meadow pipit, western yellow wagtail and northern lapwing prefer areas with permanently short vegetation. Low, reed-like vegetation with open, muddy patches of soil are particularly desirable breeding sites for the northern firmoss. However, mowing also has an inhibiting effect on the fauna through direct physical damage (injury/death). In addition, the removal of above-ground biomass restricts the development of shade-loving and litter-degrading species in particular. Without a dense litter cover, certain bird species such as common reed bunting will not find nesting opportunities. To mitigate the inhibitory effects, the use of biodiversity-friendly technology (e.g. oscillating instead of rotating mowers, high cutting), the creation of one-year rotation, the biodiversity-promoting design of ditches (e.g. one-sided ditch maintenance) and the observance of adapted periods of use are recommended.

5.5.3 Energy from biomass

Bioenergy is the useful energy that can be derived and supplied from biomass. Biomass obtained from paludiculture can be converted into various forms of useful energy. The type of conversion is determined by a number of conditions such as the utilised biomass, the desired form of energy, economic necessities, and environmental standards. The following sections introduce the various technical ways of energy supply in form of heat, electricity or liquid, as well as gaseous fuels from biomass grown in paludiculture. As the refining process is largely determined by the end use of the energy carriers, the processing methods are discussed in the context of their final use as end or net energy. The discussed methods are those which, at the current stage of technology, are economically viable for biomass from paludiculture. Biomass has a higher oxygen content in comparison to fossil fuels; also, the carbon in the biomass is partially oxidised. Therefore, the energy yield of biomass per unit mass is lower than that of fossil fuels (Hartmann 2009). For herbaceous biomass in particular, the low energy density impedes its economic utilisation as a fuel (Hering 2012, Lenz 2012).

Compaction enhances transportability, simplifies handling and, due to physical homogeneity, increases control over dosing. Consequently, compaction is often unavoidable due to economic (e. g. transport and storage costs) and technological reasons (e.g. automatic feeding and regulation of the conversion plant) (Hartmann 2009). Compaction does not affect the fuel characteristics and, besides a small reduction of the water content, only the physical and mechanical properties are altered. However, the process increases the chemical homogeneity of the biomass, which enables a better adaptation of the combustion equipment to the fuel type, and improves the energy efficiency of the biomass as a fuel. The most feasible kinds of energetic utilisation of biomass from paludiculture are direct combustion and biogas production.

5.5.4 Combustion

Combustibility of energy crops has been studied above all for crops cultivated in mineral soils and rarely for wetland plants, such as that for Phragmites australis grown on rewetted peatlands (Wichtmann et al. 2012; Kaltschmitt et al. 2009; Dahms et al. 2017b). As reported in the literature, biomass combustion is significantly affected by plant chemical composition and ash content (Wichtmann et al. 2016a; Heinsoo et al. 2011).

Herbaceous biofuels usually have higher ash contents than woody ones, thus requiring ash cleaning during combustion, and critical ingredient levels in ashes are higher (Wenzel et al. 2022). Moreover, the herbaceous biomass has a higher particle-forming tendency, which may lead to environmental and health problems, and requires additional equipment to existing techniques (e.g. additional filters) to avoid a significant reduction in the lifetime of the equipment and high maintenance costs (Giannini et al. 2016; Wulf et al. 2008; Tonn et al. 2010).

Although combustion techniques are developing steadily, reduction of nitrogen oxides remains a critical issue in biomass combustion. Emissions of nitrogen oxides NO and NO_2 are directly related to nitrogen concentration in the biomass, while high concentrations of sulphur (S) and chlorine (Cl) can increase emissions of hydrogen chloride (HCl), dioxins (PCDD/F) and sulphur oxides, and increase the risk of particle formation and corrosion (OBERNBERGER et al. 2006). High potassium (K) and sodium (Na) concentrations decrease ash-melting temperatures, while calcium (Ca) and magnesium (Mg) increase them (Kaltschmitt et al. 2009). Herbaceous biomass ash has high K and low Ca concentrations, while wood biomass ash has low K and high Ca concentrations (Bryers, 1996). Consequently, herbaceous biomasses usually have low ash-melting temperatures, which can lead to ash slagging in the boiler during burning.

Properties of solid biofuels differ not only due to the plant species from which they are derived but also due to the growing season and selected harvest date (Wenzel et al. 2022; Giannini et al. 2016). While woody crops must be harvested during dormancy (winter), when most nutrients and carbohydrates have been translocated to below-ground biomass (Zegada-Lizarazu et al. 2010), different harvest dates for grasses can lead to significant differences in biomass quality (Wenzel et al. 2022).

Many authors have observed that summer-harvested biomass has high water contents because plants store water in tissues, especially at the peak of the growing season. Therefore, drying in the field or additional pre-drying before storage is necessary before further use. Biomass water contents >20% can negatively affect both storage and net calorific value. Later harvest of herbaceous biomass is recommended if using it as biofuel for direct combustion, because lower ash content and chemical-element concentrations improve combustion quality (Hadders and Olsson 1997), (Giannini et al. 2016; Obernberger et al. 2006; Oehmke et al. 2020).

Combustion

A number of different technologies are available that can be used for paludi-biomass combustion and gasification, many of them based on long time experience in Denmark and Germany in using straw from grains or miscanthus (Miscanthus spp.) as energy source. The plant shown in Figure 5 can use either loose biomass or big quadratic or round bales. Big bales require disintegration in a scraper or disintegration unit (photos in the "Malchin" case). Blowing into a cyclone is necessary to overcome the fire wall, which itself is necessary for the

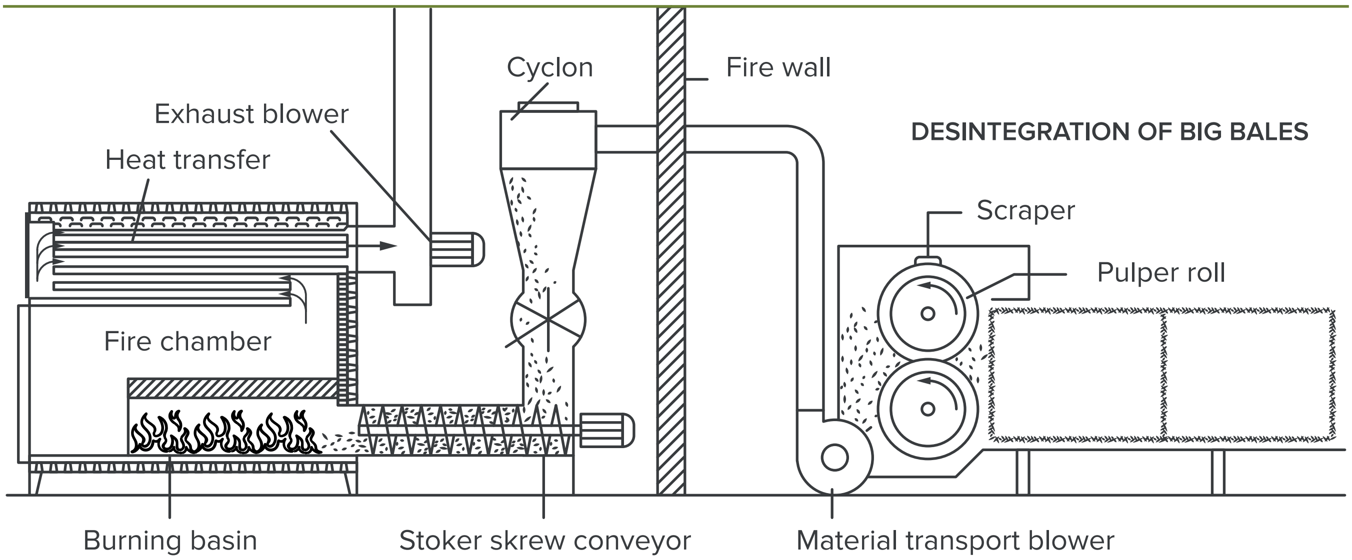


Fig. 5.
Common straw combustion plant with disintegration unit for big bales

separation of different chambers for storage and combustion. In case of loose biomass, the disintegration process is not necessary, but it is necessary that the biomass is available in chopped form. Such biomass can be obtained using special harvesting machines, equipped with chopping device and trailers. The bottleneck may be the biomass transport blower. Trials with biomass from rewetted peatlands, mainly Phalaris arundinacea and Phragmites australis with humidity of about 25% led to blockages during the disintegration process in the scraper. Moreover the biomass was too heavy for lifting by the material transport blower. This means that for good functionality, the biomass must be air-dry and uniform (Wichtmann & Tanneberger 2019, unpublished data).

Trials with reed and sedges showed good results. They can be used both for combustion and combined combustion in Ukraine for use of biomass from rewetted peatlands. Straw from grain produced on arable land could serve as a substitute if, by any reason, paludi-biomass would not be available.

The two main combustion types are fixed bed combustion and fluidised bed combustion. In fixed bed combustion (German: "Festbett-Feuerung"), air is primarily supplied through the grate from below, and initial combustion of solid fuel takes place on the. This allows for secondary combustion in another chamber above the first where secondary air is added. The two main types of stokers are underfeed stokers (German: "Unterschubfeuerung") and grate firings ("Rostfeuerung"). Underfeed stokers are relatively cheap, but only suitable as small-scale systems. They have the advantage of being easier to control than other technologies, since load changes can be achieved quickly and with relative simplicity due to the fuel feed method. Fuel is fed into the furnace from below by a screw conveyor and then forced upwards onto the grate where the combustion process begins. Underfeed stokers are limited to low ash content fuels such as wood chips due to ash removal problems. Grate firings are used either with fixed or moving grates. In contrast to underfeed stokers they can accommodate fuels with high moisture and ash content. The fuel must be spread evenly over the grate surface in order to ensure homogenous and stable combustion.

In one of the studies, the heat and power co-generation plant in Friedland, Germany (Figure 6), usually run by chipped wood, was tested by using a mix of wood chips and reed canary grass bales 1:5 (weight proportion) from Peene valley peatlands, Northeastern Germany. Differences in volume and humidity content led to difficulties in the combus-

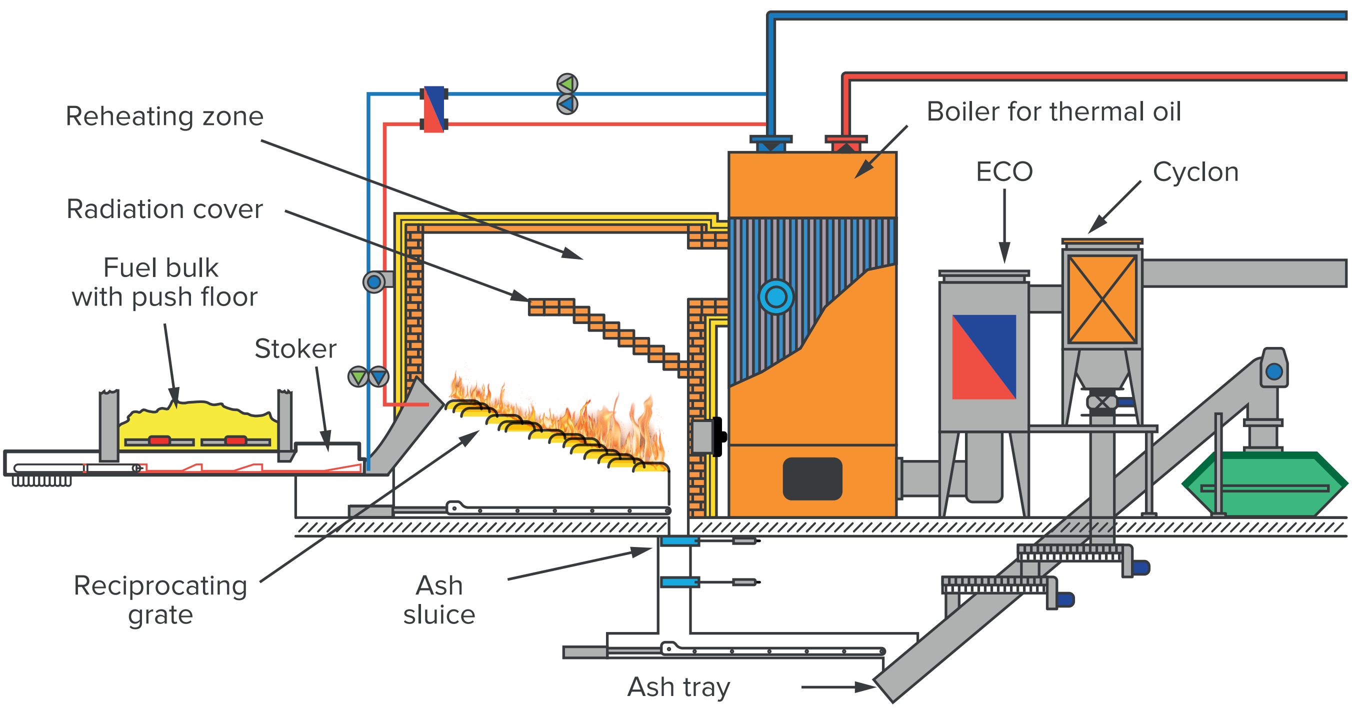


Figure 6.
Reciprocating grate firing with sloping grate installed on co-generation plant in Friedland, Mecklenburg (Germany); (Wichmann & Wichtmann 2009)

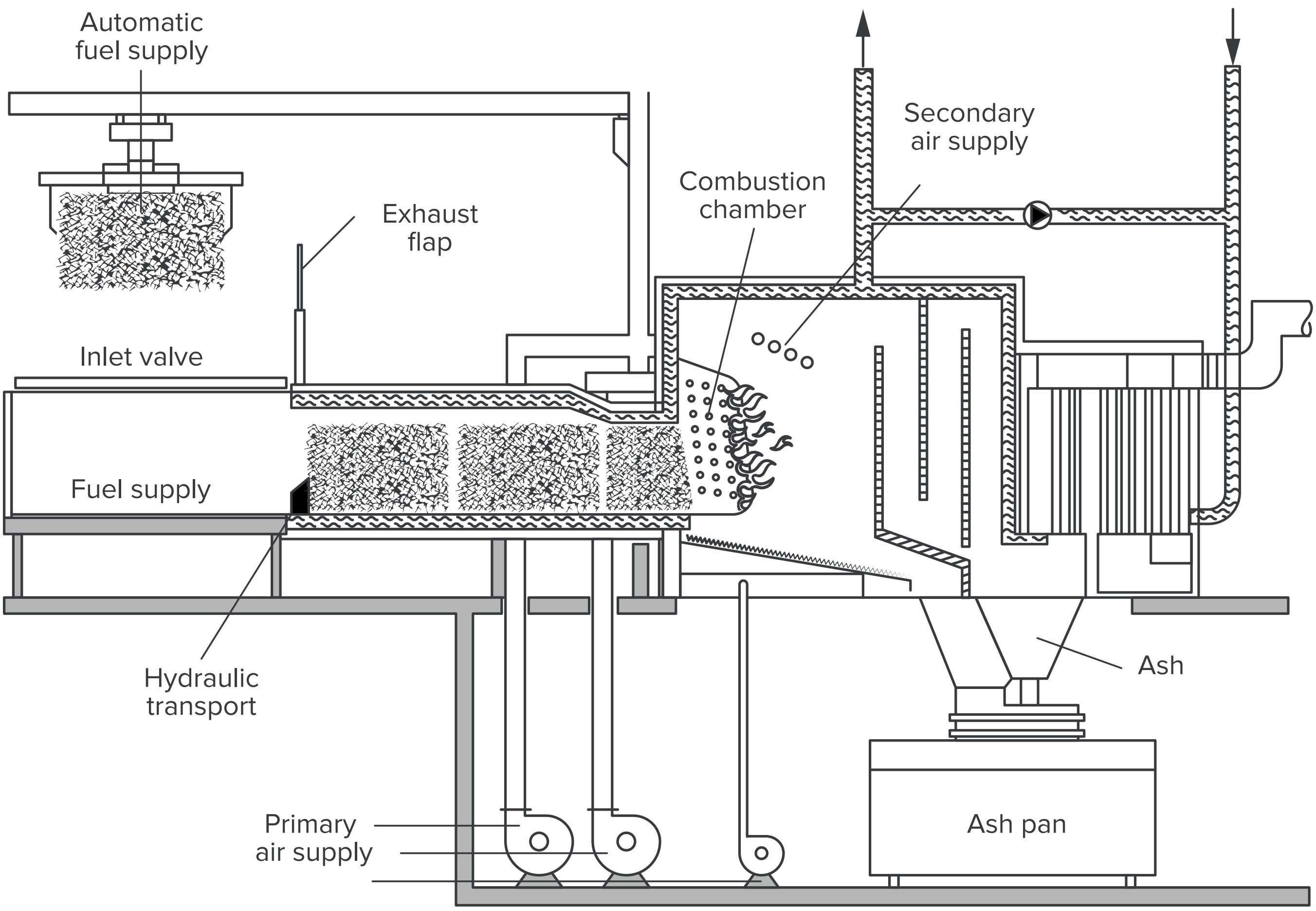


Figure 7.
"Cigar" burner for big biomass bales (Kaltschmidt et al 2009)

tion process, and the energy density of the supplied biomass mixture was too low (Wichmann & Wichtmann 2009).

This shows that loose gramineous biomass (Phalaris arundinacea) can only be mixed in low percentages to wood chips because of physical problems in charging the oven and suboptimal burning process and by that paludi-biomass can only be used for co-firing. If you work exclusively with biomass from wetted peatlands, you will have to compress the biomass into briquettes or pellets beforehand. Pellets or briquettes produced from this kind of biomass could replace the wood chips by 100% without major problems. The handling of higher ash amounts (compared with pure wood) could not be tested within the trials. The results show that existing co-generation plants that are optimised for chipped wood could be co-fired with biomass pellets or briquettes as a mono-fuel.

Furnaces with a frontal combustion (cigar burner) can be fed with entire large bales of biomass. These bales can be burnt directly without preliminary processing in a disintegrator. Another advantage is that the fuel is introduced at a higher density (Figure 7). The advantage of the associated low expenditure for fuel preparation is offset by the disadvantage of a very narrow fuel band as well as the need to produce bales of specific, clearly defined dimensions (Kaltschmidt et al 2009).

Fluidised bed combustion systems ("Verfeuerung im Wirbelschichtverfahren") operate in a different manner from fixed bed furnaces and have a number of advantages. Fluidized bed systems are flexible in the kind of fuel which is fired, which makes them suitable for co-firing different kind of fuels. Carbon burnout efficiency is very high in fluidized bed systems. Another important advantage is the possibility to control NOx generation by low combustion temperatures and to minimize SOx generation in the case of fossil fuel co-firing. A disadvantage of fluidized bed systems is their high fan capacity requirement to provide for the fluidizing air. There are two main types: bubbling fluidised bed (BFB, "Stationäres Wirbelschichtsystem"; lower capital requirement) and circulating fluidised bed (CFB, "Zirkulierendes Wirbelschichtsystem"; better carbon burnout efficiencies and better in absorbing acid gases). Plants already existing could use paludi-biomass as co-firing material or as a mono-fuel. They could change their supply sources from day to day following the offers on the market (Wichtmann & Tanneberger, 2009).

Biomass gasification

A widespread big bales biomass gasification device for clean combustion of materials like straw and hay is the "Herlt Ganzballenvergaser" (round bale gasifier). It has a large gasifier cavity with ceramic insulation coatings and can be fed by whole big bales. Thus heat leakage is low and optimal temperatures for the gasification process are warranted. A rich gas fuel (with high percentages of CO, H_2, CH_4) and only low CO_2 and N_2O emissions is produced. Due to the low gasification velocity of the bales at temperatures >500°C, the ashes remain in the gasifier cavity and do not reach the main burning chamber. Thus, the produced gas is burnt at temperatures of maximum 1,300°C without any slagging. These gasification units can be used for many purposes, e.g. as hot water boilers (85-2,000 kW) or heat and power co-generation plants combined with a steam engine (328 kW, 600 kW, 1200 kW).

For the fuel supply, the gasification unit would require compaction of the biomass from the rewetted peatlands to big bales by either using a modified snowcat with compression baler or, on frozen soil, common hay making tractors and balers (Wichtmann & Tanneberger, 2009).

Preparation of the fuel

Danish Linka heating facilities can be used for loose biomass combustion (see "Malchin" case). These were originally developed for straw. Big bales can be burned directly e.g. in Herlt gasifiers (round bales) or in cigar burners. Most of the added value has biomass that is compressed into pellets or briquettes. Therefore, the EU project "Wetland Energy" aimed at demonstrating the production of briquettes from biomass from wet peatlands. Briquettes are better suited for combustion than smaller fractions. Homogenous coarse powder from Phalaris arundinacea grass resulted in higher ash and silica contents (causing damage in the combustion chamber) than briquettes produced from the same species. The major advantage of gasification is that the quality required is lower than that for combustion (humidity 20–25% for Herlt gasification). Lower water contents are suboptimal for the gasification process because the temperatures of about 500°C developing at the margins of the bales cannot be conducted into the core of the bale. Reed from winter harvest is very suitable for gasification because of its high cellulose content. The main quality requirements regarding biomass for combustion are (Wichmann & Wichtmann 2009):

- High heating value;
- Low water content (except for Herlt gasifier);
- Low content of problematic substances (Cl, S, N, Si);
- Low ash content;
- High ash melting temperature;
- Appropriate conditioning;
- Low emissions.

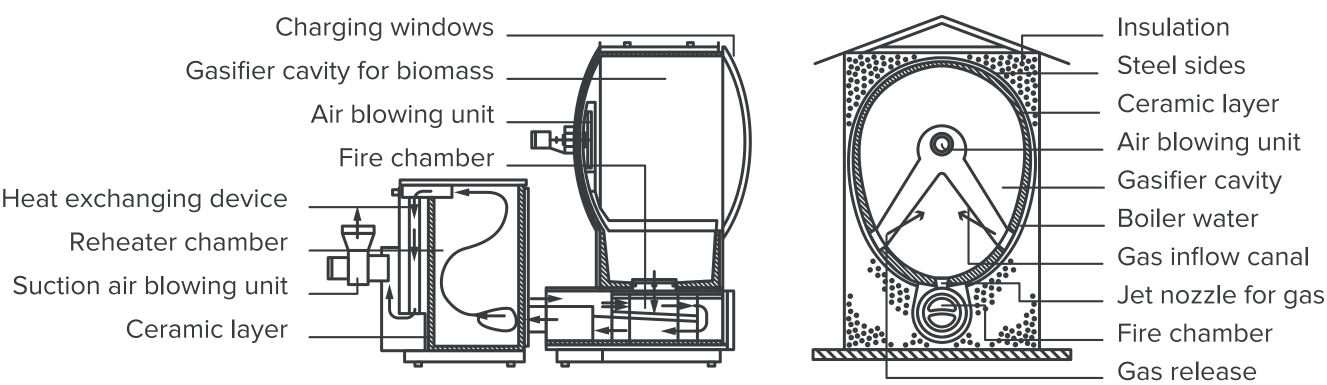
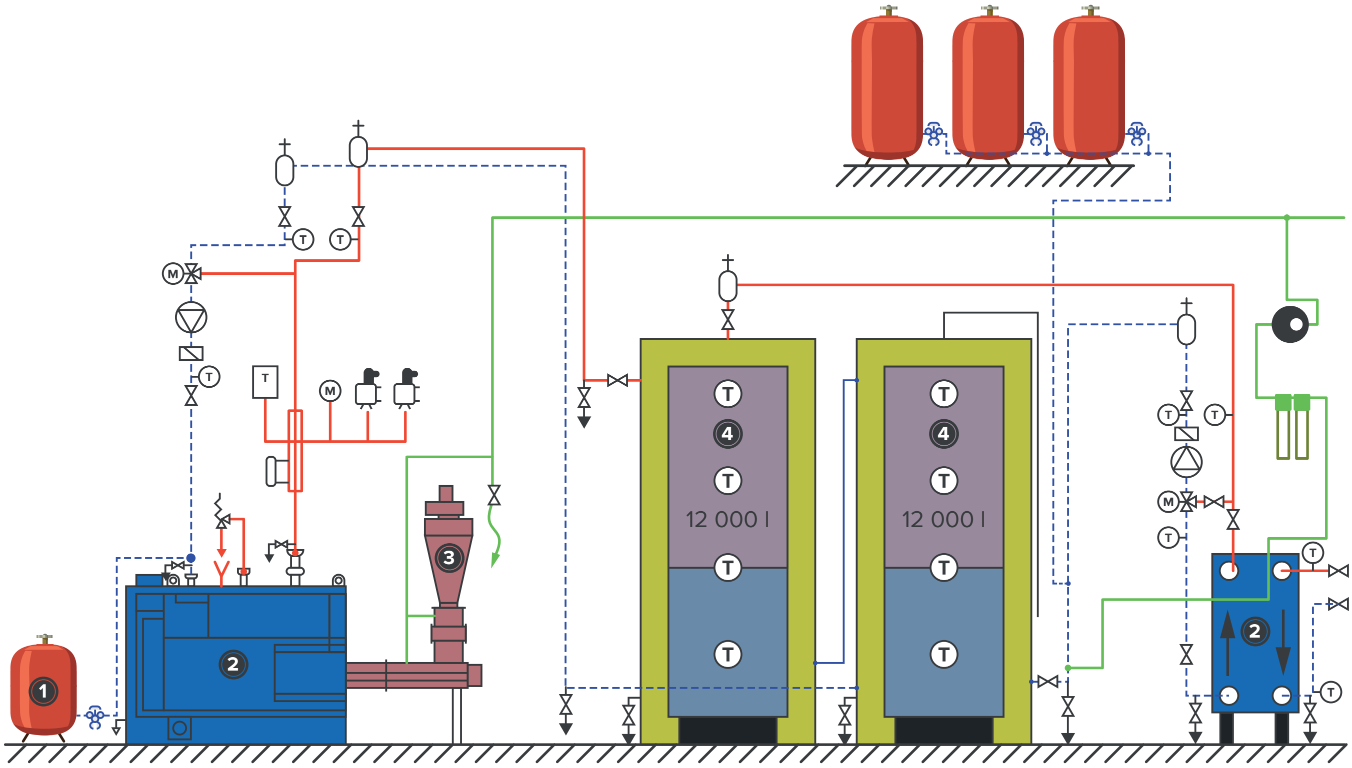


Figure 8.
Working principle of the Herlt biomass gasification plant, front and lateral view (HERLT SonnenEnergieSysteme).



1 800-liter air pressure buffer
2 Boiler manufactured by Linka
3 Cyclone for feeding the crushed biomass into the boiler and to prevent flames from entering the biomass feed system
4 Buffer tanks for storing heat in water

Figure 9.
Diagram showing the 800 kW biofuel combustion unit installed at Malchin, Germany (Wichtmann 2021)

5.5.5 Case study: Malchin heating plant from paludiculture guide

"Malchin Heating Power Plant – Added Value and Climate Change Mitigation", Tobias Dahms and Anke Nordt

A pioneering concept for the utilisation of biomass from rewetted peatlands is the close cooperation between the agricultural enterprise Voigt and the local energy supplier Agrotherm GmbH, who opened a heating plant to supply a district heating network for the town of Malchin, in the German federal state of Mecklenburg-West Pomerania.

As a result of a major fen restoration project (Peenetal/Peene-Haff-Moor), the fodder quality of the pastures used by farmer Voigt declined, which frustrated the continuation of grazing with suckler cows. In order to continue farming on the rewetted sites, a concept for the thermal utilisation of the biomass was developed since 2006.

An ideal opportunity was the short distance to the town of Malchin, which is situated 12 km from the farm and had a district heating network that solely operates with natural gas. It was possible to utilise regional biomass from sedges, rushes and reed canary grass by integrating a biomass boiler into the district heating network. The biomass of some 300 hectares are now annually used to produce 800–1000 t fuel, which equals 2,900–3,800 MWh or 290,000–380,000 l of heating oil. The plant currently provides district heating to 543 standard flats, two schools, and a day-care facility for children. The biomass boiler is made by the Danish company LIN-KA/Danstoker and has a thermal capacity of 800 kW. The boiler has a water-cooled, movable step grate combustion system which prevents the formation of slag and ash deposits. Long residence times and the re-circulation of the exhaust gasses into the combustion chamber minimise the emission of harmful substances. Dust particles are removed by a multi-cyclone system coupled with a downstream fabric filter. The generated heat is transferred into a 24,000 l thermal storage tank, which is used to cover the base and medium load range. The local energy supplier guarantees the purchase of at least 4,000 MWh in the form of heat, which is equivalent to about 5,000 peak load operating hours per year. A gas boiler covers the peak load and the maintenance hours of the biomass boiler.

The required biomass is harvested by Voigt agricultural business during dry periods in summer using adapted machinery, then is pressed into round bales and transported to the boiler site. There, the bales are fed continuously into the boiler of the district heating plant with a conveyor belt, which can hold 24 bales of biomass. In winter, the boiler system is fed on a daily basis. The bales are shredded, and the loose stalks are transported via a double worm feeder and a screw stoker into the combustion chamber. The ash is automatically removed. Apart from biomass from wet fen peatlands, the boiler can also use straw as a fuel and – with a separate feeder, also wood chips. The investment costs for a biomass boiler, particularly for herbaceous biomass, are significantly higher than for boilers operated on fossil fuels (FNR 2007). The net investment for the combustion plant (including fuel processing, flue gas fans, buffer store and installation) amounts to 630 EUR/kW of nominal heat output. Additionally, funding is needed for the building shell, chimney, storage and machinery. However, the great advantage compared to fossil fuel boilers is the much lower fuel cost. Agrotherm GmbH calculates fuel costs of 3.9 EUR per provided GJ of heat (Bork 2013, personal communication). Altogether, there is the advantage of reduced net heat production costs and long-term price stability. The energy concept of Malchin shows how local networks may contribute to the implementation of pilot projects and is an inspiring example for many other regions.

5.5.6 Life cycle analysis (LCA) for combustion of biomass from paludiculture

By substituting natural gas with grass biomass in the district heating network of the town of Malchin, according to modelled calculations, taking into account the energy bound during photosynthesis and the bound carbon, 1.08 GJ of primary energy and 60 kg CO_2-eq. are saved per GJ of fuel used. Thus, the utilisation of grass-like that biomass, e.g. mire biomass, achieves savings just as high as the use of forest woodchips. Per year, this corresponds to 15.5 TJ or 850 tonnes of CO_2-eq. and the water level rise and its retention caused by this saves around 3,000 tonnes of CO_2 eq. per year. Only direct inputs and outputs were taken into account for calculation. As the areas have already been rewetted for nature conservation reasons and the biomass is unsuitable for animals, no direct or indirect land use changes are taken into account (Dahms et al. 2012).

Life cycle assessment is an evaluation procedure in which the environmental impact of a product is systematically recorded and balanced over its entire life cycle.

The life cycle analysis has shown that the primary energy consumed during the analysed life cycles is only a minor part of the energy chemically bound in the biomass. Energy consumption and greenhouse gas emissions follow similar patterns. Heated air drying of biomass causes the highest expenses during the life cycle path. 15% of the energy content of the biomass is needed for warm air drying. Pelletizing consumes energy which equals about 10% of the biomass energy. Expenses for harvest and transport of the biomass are relatively small. If drying is not consid-

Photos 19-21:
From left to right: Disintegration unit for chopping hay from wet meadows (Wichtmann 2021). Conveyer for transporting opened round bales to the disintegration unit (Wichtmann 2016); Linka straw-oven (boiler), adapted for the combustion of hay from paludiculture

ered, baling the biomass is superior to pelletizing. The reduced primary energy demand and greenhouse gas emissions during transport of pelletized biomass cannot compensate for the efforts of pellet production. However, drying is the crucial factor determining the life-cycle comparison. The significantly lower demands of cold air drying of biomass in scenario CR 2 (see Figures 11 and 12) leads to the highest savings of all scenarios despite pellet production. The substitution of hard coal by biomass from rewetted peatlands as fuel in power plants leads to significant reduction of primary energy depletion and greenhouse gas emissions. These savings are additional to and in the same order of magnitude as possible emission reductions from rewetting drained peatlands (Dahms 2012). Figure 11 shows the primary energy consumption and greenhouse gas emissions connected to single life cycle steps where Reed Canary Grass (RCG) and Common Reed (CR) are harvested as round bales by using adapted grassland machinery (scenarios RCG 1, RCG 2, CR 1). In scenario 2 Reed Canary Grass and Common Reed are harvested by a tracked vehicle.

The utilisation of biomass from paludiculture leads to considerably less greenhouse gas emissions and fossil fuel depletion than the use of hard coal. If hard coal is substituted by biomass from rewetted peatlands, between 82% and 92% of the greenhouse gas emissions and between 70% and 83% primary energy depletion can be avoided.

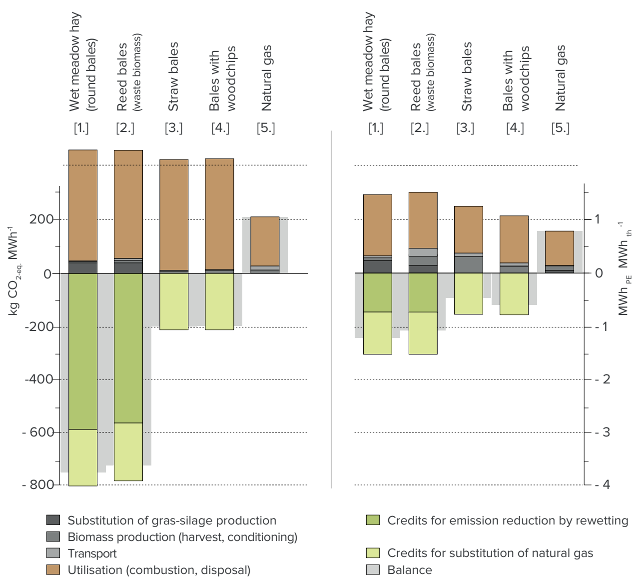


Figure 10:
Comparison of the greenhouse gas and energy balances of different fuels

It is likely that biomass produced as a result of paludiculture can be used as co-fuel in peat fired power plants as well. This would lead to even higher reductions of greenhouse gas emissions, since peat-firing results in higher greenhouse gas emissions per GJ than hard-coal-firing. Best results can be achieved if energy intensive heated air drying is avoided and the biomass is harvested and transported as bales. Pelletizing is connected to high energy consumption and is unreasonable if only the life cycle analysis perspective is considered.

5.5.7 Biomass fuel and climate protection – advantages of grass-like biomass over wood

While grass like biomass has significantly less favourable combustion properties than wood, it offers considerable advantages from a climate protection point of view. In many cases, biomass combustion causes higher greenhouse gas emissions per unit of energy than fossil fuels, as the primary energy content is lower in relation to the carbon content. At the same time, biomass combustion also achieves a lower conversion efficiency than fossil fuels. All in all, this means that, in the worst-case scenario, burning biomass can cause more than 1.5 times the amount of greenhouse gas emissions compared to fossil fuels for the provision of the same amount of heat/secondary energy. The assumption that the release of carbon dioxide (CO_2) bound in biomass can be regarded as neutral in all cases is incorrect, as described by various authors. The decisive factor is how quickly the carbon stock released during combustion is restored. For example, how quickly a forest grows back or how quickly the carbon bound in the plant would be released if it were not used as fuel (e.g. through decomposition). However, other effects such as the loss of soil carbon and land use changes etc. must also be taken into account. This carbon debt of biomass must first be offset before the emissions can be considered neutral. Only then biomass combustion offers an advantage over fossil fuels. In the case of stem wood, it takes around 50 years and at least a decade for residual wood until this point is reached (Wenzel et al. 2022).

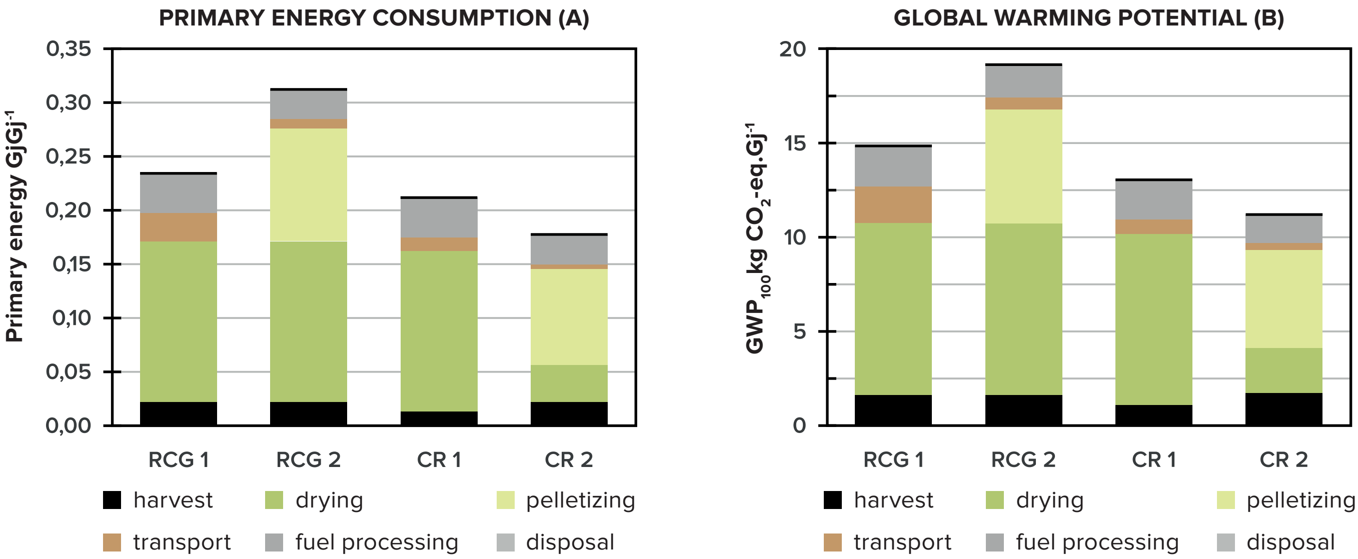


Figure 11 and 12:
Primary energy consumption (A) and global warming potential (B) differentiated by scenario and life cycle stages. For clearness, combustion is not depicted (see Figure 3). Reed Canary Grass (RCG) and Common Reed (CR)

It should also be taken into account that if the biomass is utilised in an alternative way, e.g. as a building material, the carbon remains sequestered for decades. It may also be possible to replace building materials production of which already causes significantly higher greenhouse gas emissions. For example, the use of wood products can save an average of around 4 kg of CO_2 per kg, while the substitution of natural gas can avoid 0.85 kg of CO_2 per kg of wood in the most favourable case. If such an alternative material utilisation is possible, biomass fuels also perform poorly compared to natural gas or heating oil. In comparison to wood, the considerable advantage of straw materials is that they decompose within a few years if they are not used and a large proportion of the bound carbon would be released back into the atmosphere. In many cases, there is also no alternative use for grasslike biomass or it is possible to utilise residual materials that arise from higher-value utilisation (e.g. remnants from cleaning bundles during thatch reed production (Wenzel et al. 2022).

Thermal energy from biomass

Thermal energy from biomass is the main form of energy from biomass in Ukraine (94% of all bioenergy consumed in 2018)[6].

Specially grown energy plants or the remains of agricultural crops or wild plants, including paludiculture crops such as common reed and biomass from wet meadows can be used for the production of thermal energy from biomass.

Biomass can be used without processing (wood chips and plant bales are burned), or biomass can be briquetted or pelletized, which is more advantageous for transporting raw materials over long distances.

Energy plants are annual and perennial fast-growing crops that can be used as biomass or for the production of biofuel. The main advantage of growing energy plants is high mass productivity per unit area in a limited period of time (10-25 t/ha^{-1} yr^{-1}) and a long period of use (up to 30 years).

In Ukraine, only 3.5 thousand hectares of land are allocated for energy plants. Part of the plantations is in experimental operation, and the other part is used for commercial cultivation of willow, poplar and giant miscanthus [7].

6 https://uabio.org/biomass-heating/

7 https://saf.org.ua/news/1734/

Specially bred plant varieties are used for plantations. The Ministry of Agricultural Policy of Ukraine maintains the State Register of plant varieties suitable for use in Ukraine, including energy plants. The updated Register was officially published in June 2023 and contains 36 varieties of energy plants, including 18 varieties of three species of willows: crack willow, osier willow and almond willow [8]. The list of varieties is given in Annex 1.

5.5.8 Biogas

(Eller et al. 2020; Czubaszek et al. 2021; Czubaszek et al. 2023)

The key factor in sustainable biogas production is a feedstock the production of which has no adverse impact on the environment. Due to the rising prices of maize and the decreasing social acceptance of maize as a sustainable feedstock, biogas plant operators seek inexpensive feedstocks that could substitute maize silage (MS). Reed biomass is a lignocellulosic material that is inexpensive, not competing with food production and, in some cases, also considered a waste that it is challenging to utilize. Common reed is an invasive species mown as part of wetland conservation measures, or it can be harvested from paludiculture (Czubaszek et al. 2023).

Biomethane

Biomethane (CH_4) production from such species as common reed (Phragmites australis), broad-leaved cattail (Typha latifolia), narrow-leaved cattail (Typha angustifolia) and giant cane (Arundo donax) has been investigated. Biomethane production was measured in four independent batch digestion tests. Across all experiments, fertilization regime had little effect on CH_4 yield, which was on average 222 ± 31 L/kg of volatile solids (VS). The lowest yield was produced by Typha angustifolia (140 L /kgVS) receiving no nutrients, while the highest yield was produced by Arundo donax (305 L/kgVS) in the highest nutrient treatment. The intraspecific diversity of P. australis did not affect biomethane production. All P. australis genotypes produced on average 226 ± 19 L CH_4 /kgVS, which, although high, was still lower than conventional biogas species. The biomass production of P. australis was less increased by fertilization than that of Typha sp. and A. donax, but all species had similar biomass without fertilization. Phragmites australis, Typha latifolia, T. angustifolia and Arundo donax (Eller et al. 2020).

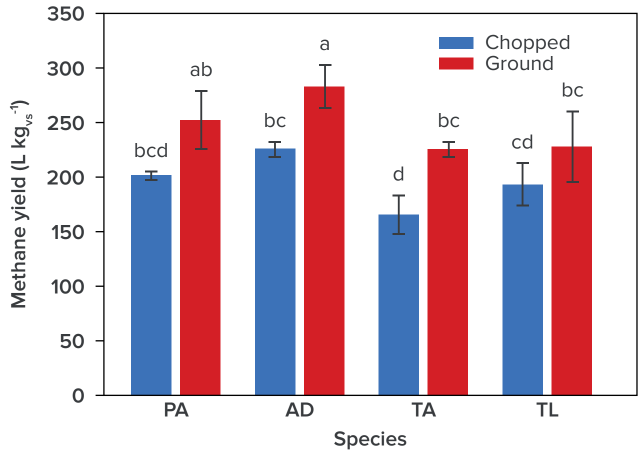


Figure 13:
Biomethane yield (mean ± standard deviation) of different wetland plant species (PA: Phragmites australis, AD: Arundo donax, TA: Typha angustifolia, TL: Typha latifolia). Shoots were fermented as chopped or ground material. Plants were fully fertilized with an equivalent of 500 kg N ha^{-1} $year^{-1}$. Different letters indicate statistically significant ($p < 0.05$) differences between means based on Tukey's post-hoc test. VS: volatile solids (Eller et al. 2020).

Figure 13 shows that crushing biomass before fermentation has a rather positive effect on the amount of biogas produced.

Specific methane yield

(Czubaszek et al. 2021)

The specific methane yield of selected wetland species subjected to wet and dry anaerobic digestion was evaluated: Carex elata All. (CE), a mixture (~50/50) of Carex elata All. and Carex acutiformis (CA), Phragmites australis (Cav.) Trin ex Steud. (PA), Typha latifolia (TL) and Phalaris arundinacea (PAr). The plants were harvested in late September, and therefore, the study material was characterised by high lignin content. The highest lignin content (36.40 ± 1.04% TS) was observed in TL, while the lowest (16.03 ± 1.54% TS) was found in CA. PAr was characterised by the highest hemicellulose content (37.55 ± 1.04% TS), while the lowest (19.22 ± 1.22% TS) was observed in TL. Cellulose content was comparable in almost all plant species stud-

8 https://saf.org.ua/news/1734/

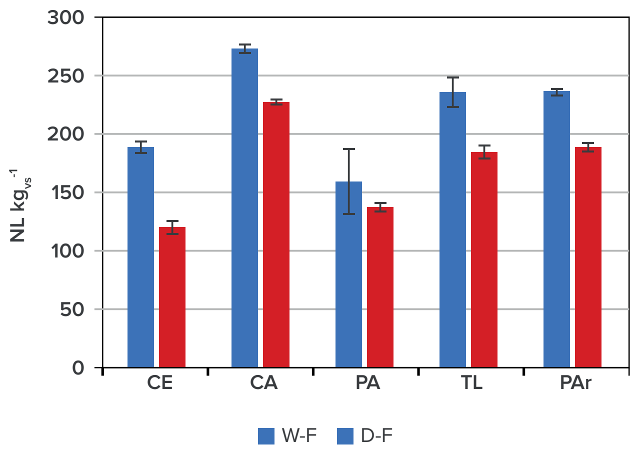


Figure 14:
Specific methane yield (SMY) produced by both types of fermentation: W-F – wet fermentation; D-F – dry fermentation. CE – Carex elata; CA – Carex acutiformis + Carex elata; PA – Phragmites australis; TL – Typha latifolia; Par – Phalaris arundinacea. Standard errors are shown as vertical bars (Czubaszek et al. 2021).

ied and ranged from 25.32 ± 1.48% TS to 29.37 ± 0.87% TS, except in PAr (16.90 ± 1.29% TS).

The methane production potential differed significantly among species and anaerobic digestion (AD) technologies. The lowest SMY was observed for CE (121 ± 28 L/kgVS) with dry fermentation (D-F) technology, while the SMY of CA was the highest for both technologies, 275 ± 3 L/kgVS with wet fermentation (W-F) technology and 228 ± 1 L/kgVS with D-F technology. The results revealed that paludi-biomass could be used as a substrate in both AD technologies; however, biogas production was more effective for W-F technology. Nonetheless, the higher methane content in the biogas and the lower energy consumption of technological processes for D-F suggest that the final amount of energy remains similar for both technologies. The yield is critical in energy production by the AD of wetland plants; therefore, a promising source of feedstock for biogas production could be biomass from rewetted and previously drained areas, which are usually more productive than natural habitats (Czubaszek et al. 2021).

The amount of energy that can be produced from wetland plants depends on their yield. Natural habitats are usually less productive. Regardless of that, if these habitats are mown, the utilisation of biomass as a substrate for biogas production is an alternative to, for example, disposal of biomass at the edge of the field or composting.

The situation is different in the case of habitats created by the rewetting previously drained areas. The yields here are significantly higher, which means that the energy obtained may be even close to that of maize. This makes the rewetting and implementation of paludiculture more attractive for producers. At the same time, utilization of paludi-biomass as an AD substrate may reduce maize cultivation on fertile mineral soils and make these sites available for food production – in favour of paludiculture on rewetted peatland sites (Czubaszek et al. 2021).

Table 5.
Energy from anaerobic digestion (AD) of paludi-biomass from highly productive paludiculture calculated on the basis of BMP results and assumed high yields

PLANT SPECIES	Electricity Production from AD		Heat Production from AD	
	W–F	D–F	W–F	D–F
	kWh/ha		GJ/ha	
Carex elata (CE)	6332	4386	19.84	16.64
Carex acutiformis + Carex elata (CA)	5981	5403	18.74	20.50
Phragmites australis (PA)	6870	6431	21.52	24.40
Typha latifolia (TL)	12.567	10.679	39.37	40.52
Phalaris arundinacea (PAr)	9610	8326	30.10	31.60
Maize	13.622	–	42.69	–

W-F – wet fermentation; D-F – dry fermentation.

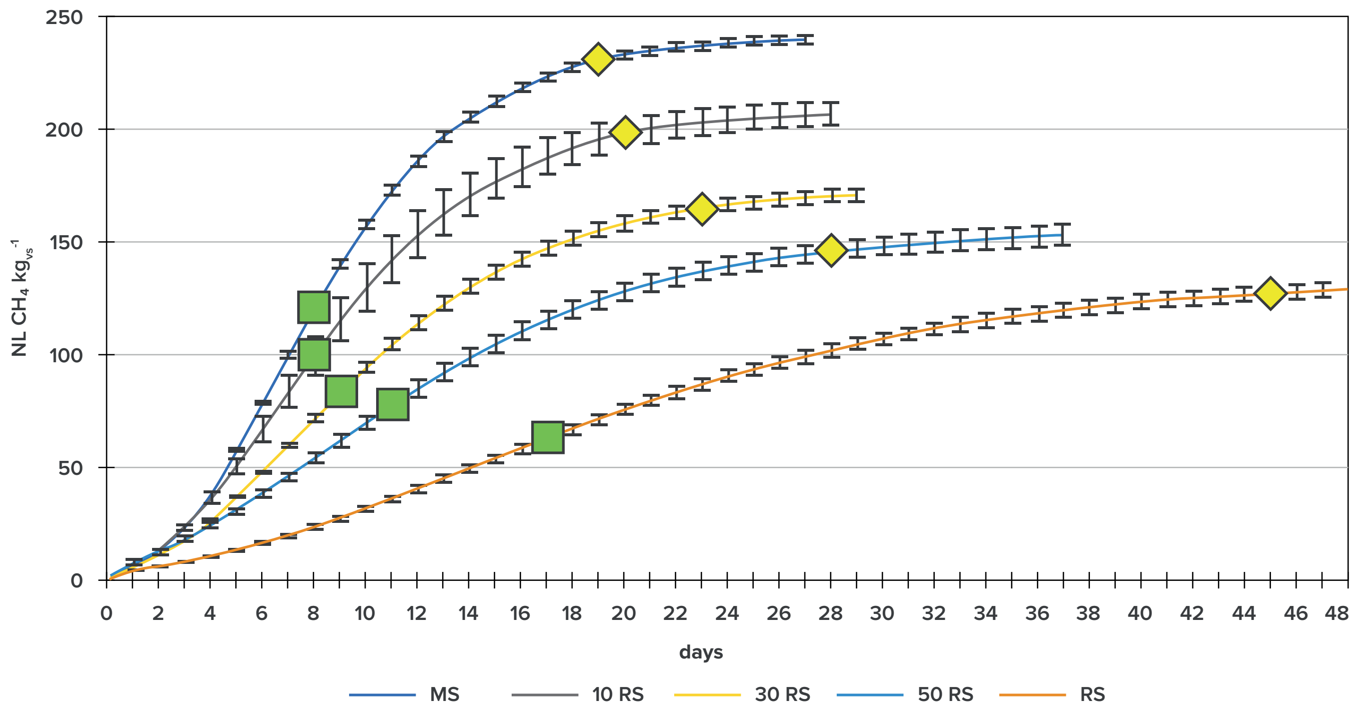


Figure 15. Cumulative methane production from mono- and co-digestion of maize (MS) and reed silages (RS).

MS – maize silage.
10 RS – maize silage with 10% content of reed silage.
30 RS – maize silage with 30% content of reed silage.
50 RS – maize silage with 50% content of reed silage.
and RS – reed silage.

The green squares and yellow diamonds mean T50 (time required to produce 50% of the total potential methane yield) and T95 (time required to produce 95% of the total potential methane yield), respectively. Standard errors are shown as vertical bars (Czubaszek et al. 2023).

Use of several cultures

A study conducted by Czubaszek et al. 2023 aimed to investigate wet co-digestion of maize silage with 10%, 30%, and 50% content of common reed silage using the biochemical methane potential (BMP) test. In addition, the potential energy generated and avoided greenhouse gas (GHG) emissions were calculated. The substitution of maize silage with 10%, 30%, and 50% content of reed silage reduced the methane (CH_4) yield by 13%, 28%, and 35%, respectively.

A disadvantage of reed silage addition was increased ammonia (NH_3) and hydrogen sulphide (H_2S) concentrations in biogas. Substituting maize silage with reed silage decreases the CH_4 yield, but the co-digestion of maize and reed biomass from conservation or paludiculture may positively affect environmental aspects of energy generation. The substitution of maize with reed in biogas plants decreases the area used for maize cultivation and reduces greenhouse gas emissions. Adding reed as a maize substitution may significantly impact the environmental performance of biogas plants since reed does not require additional new land for cultivation. Even if the CH_4 yield per hectare or ton of fresh matter is lower for reed than for maize, reed can be competitive due to lower or zero demand for agrochemical input. Reed harvested in natural habitats or from paludiculture also performs much better in terms of greenhouse gas emissions (Czubaszek et al. 2023).

Production of biomethane in Ukraine

As of 2024, biomethane production capacity in Ukraine is 6 million cubic meters /year – 3 million cubic meters/year is produced by Hals Agro holding plant in Chernihiv Oblast, and 3 million cubic meters/year is produced by Vitagro holding in Khmelnytskyi Oblast.

The cost of biomethane production ranges from €800 to €900 per 1,000 cubic meters, while natural gas costs approximately €350 per 1,000 cubic meters. Due to unprofitability, both plants were stopped. Thus, this source of energy is currently not produced on an industrial scale in Ukraine [9].

It is planned that the installation of biogas enrichment to biomethane at Hals Agro will become operational after opening the opportunity to sell this alternative fuel to Europe, where customers are ready to pay €900-1,200 per 1,000 cubic meters. Now export is impossible due to a gap in Ukrainian legislation.

According to the data by the Bioenergy Association of Ukraine, the biomethane industry in the country is developing — during 2024 – 2025, it is planned to open up to 10 new facilities with a capacity of 3 to 56 million cubic meters.

The barriers to the development of the biogas and biomethane sector include those potentially related to paludiculture: lack of experience, in particular the use of lignocellulosic materials (straw) and other raw materials from plant residues.

5.5.9 Solar power

Although not directly concerned with bioenergy production, it is worth noting that some forms of renewable energy production may be compatible with the high water table management of peatlands. As in most countries, in Ukraine peatland areas are regarded as marginal or waste land this can be bought or leased very cheaply on the land market. Their value as carbon stock, space for biodiversity, improvement of water quality and other ecosystem services does not usually play any role. This means that peatlands are regarded as replacement and reserve areas for infrastructural activities, such as the construction of roads, residential areas and also solar power plants. On the other hand, the drained peatlands often are strongly degraded or at least devastated due to long time drainage in the past, and their value because of their functions in the landscape is minimal – or the burdens they cause are far greater than their positive characteristics. This would mean that no major damage or negative impact to the ecosystem could be expected from the installation of solar systems. If the peatlands are rewetted, this in contrast has the positive effect of minimising greenhouse gas emissions from peat decomposition and gives incentives for rewetting the degraded peatland site.

In order to achieve the national climate protection targets, the measures of the various sectors must complement each other. Photovoltaic systems on rewetted peatlands can contribute to climate protection across sectors (Hohlbein 2022):

1. in the energy sector by utilising solar energy instead of fossil fuels,
2. in the land use sector by reducing CO_2 emissions through rewetting,
3. possibly in other sectors through long-term storage of carbon in paludiculture products.

Photovoltaic systems combined with peatland rewetting and biomass cultivation allow the production of renewable raw materials as an alternative to fossil raw materials and fuels, and contribute to decarbonization in the construction sector, for example, through the production of building materials.

In Germany, emissions of around 35 million tonnes of CO_2 eq. were avoided in 2020 through the use of photovoltaic systems. The complete rewetting of peatlands used for agriculture would save CO_2 emissions by the same amount. The climate neutrality intended by the Paris Agreement and the Federal Climate Protection Act means that construction and operation of photovoltaic systems on peatland soils may only take place in conjunction with rewetting of the peatland, i.e. only if permanent average water levels close to or above the peat surface are made possible (Hohlbein 2022).

Photovoltaic panels are increasingly being deployed over water bodies, and in principle the same approach could work over wet peat, with so-

9 https://agroportal.ua/news/novosti-kompanii/biometanovi-zavodi-v-ukraiini-zupinilis-virobnictvo-neviqidne?fbclid=IwAR1MI6n7Yqq489qvd3rxMp UC4ucGM71TdqRO8nJF00Gt4BbvCpv3ONpdi80

lar arrays supported on scaffolding or rail systems above the peat surface. While this would shade the ground surface, it will also enhance microclimate humidity and could aid the growth of certain paludiculture species. Sphagnum moss, in particular, grows better in partial shade than it does in full sunlight (Clymo and Hayward 1982). Spacing of the panels could be wider than normal in order to allow management and/or harvesting, but consequent reductions in energy capture would be compensated for by the combined effects of avoided emissions from the peat soil, improved efficiency of the photovoltaic panels (Chemisana and Lamnatou 2014), and the remaining carbon sequestered in the biomass when it is harvested. It may also be possible to install wind turbines in degraded peatlands within a landscape under paludiculture management, provided that this does not lead to large-scale damage of the peat.

The following instructions referring to the construction of photovoltaic systems should be followed (Hohlbein 2022):

- Photovoltaic systems should be installed primarily on roofs and on sealed and contaminated surfaces,
- Installation on degraded peatland is allowed only in combination with rewetting: the areas must be permanently rewetted, and the systems must not prevent the rewetting of neighbouring peatland areas,
- Photovoltaic systems should be installed only on peatlands within areas planned for power production,
- Photovoltaic systems should serve as a lever for larger rewetting measures in peatland areas,
- Construction measures should be implemented in a soil-conserving and peat-conserving manner,
- The formation of extensive vegetation should be ensured,
- Soil-conserving maintenance and dismantling of the photovoltaic systems should be planned from the beginning,
- Continued agricultural utilisation of rewetted peatland areas is provided.
- Monitoring should be insured for building up knowledge. Long-term monitoring should ensure that the high water levels installed using the rewetting measures are also permanently effective.

With the commissioning of the solar system, the measures for permanent rewetting should be completed. Best would be if the confirmation of rewetting from the water authority would be submitted to the grid operator at the latest at the time of commissioning (Hohlbein 2022).

5.5.10 Conclusions for energy utilisation

Biomass resulting from wet meadow management is suitable for thermal utilisation. The great potential arising from the rewetting of peatlands in Ukraine for the establishment of paludiculture production should be utilised for a wide range of possible uses of the biomass produced. When establishing paludiculture, the focus should be on the material utilisation of the biomass to be harvested. However, the rewetted areas that can be utilised are likely to be rather small at the beginning (orientation towards specific biomasses, development of markets, etc.). It is considered difficult to establish processing capacities for material utilisation in the short term (Wenzel et al. 2022).

Energy recovery has great advantages here in terms of the short-term development of land availability and biomass absorption capacity. Energy utilisation therefore has a perspective as a transitional technology: it can generate a large local demand for biomass in the relatively

Photo 22-23.
On the left: How a photovoltaic system in a rewetted peatland may look like (Moor-PV - Fraunhofer ISE);
On the right: An implemented system for continued use of peatlands for paludiculture and installing solar panels (Photovoltaik im Moor: viel Potenzial, kaum Erfahrungen - Solarserver).

short term and promote regional material flows and economic relationships. This reduces emissions in the long term through rewetting and replaces fossil fuels.

When storing the hay bales, the focus should be on optimising the water content of the biomass, but this is not possible in every harvest year. Depending on the season, excessively high water levels in the area or persistently high rainfall can thwart the optimum harvest time. In order to be able to take advantage of good weather conditions at short notice, it is important that the harvesting and transport technology available is highly effective. Even more ideal would be the availability of additional alternative utilisation options for wet or moist biomass (produce silage for biogas production instead of hay for combustion) in order to be able to operate independently of the weather conditions.

Heterogeneity, combustion characteristics, etc. make wet peatland biomass not the best energy resource. But targeted management of plant stocks, adaptation of harvesting or combustion technology can improve the quality of this type of biofuel. There are several options for influencing the quality of paludiculture biomass. On the one hand, you can choose the date of harvest and how the process will be organized, for example, leaving the biomass on the ground after mowing so that the rains leach the hay. On the other hand, you can optimize the composition of the vegetation by changing the date of harvest and, if necessary, re-mowing. Converting peatland management to paludiculture requires minimum standards (high groundwater level, adapted vegetation, low emissions, productive utilisation). This is necessary so that the ecosystem services associated with wet peatlands (in particular the reduction of greenhouse gas and nutrient emissions) can be achieved. A sufficient rise of the water table is the basic prerequisite for stopping peat mineralisation and minimising greenhouse gas emissions.

This requires optimal average groundwater levels not less than 10 cm from the ground in summer. In winter, these should always be higher in order to provide sufficient water for the summer by inundation. In this respect, the harvesting technique must be adapted to the site conditions. This is all the more important if adapted grassland technology can no longer be used due to high groundwater levels, and special technology (machines with balloon tyres or crawler tracks) must be used. Harvesting machines should be highly utilised in order to minimise the costs of providing biomass.

The use of paludiculture biomass as a fuel can also reduce greenhouse gas emissions – on the one hand by rewetting the peatland site and on the other by replacing the use of fossil fuels such as natural gas. However, these additional savings only amount to around a quarter of the savings achieved by rewetting the peatland. From an economic point of view the use of wet meadows is a challenge that is only economically viable under favourable conditions (low cost of rewetting, high price of biomass, demand for biomass and biomass products, etc.). However, it can be assumed that these conditions will change in favour of the use of biomass from wet peatland management as prices for fossil fuels rise. The social benefits of regional value creation and landscape conservation already speak for themselves today (Wenzel et al. 2022).

5.6 Utilisation of paludi-biomass for construction

5.6.1 Overview

In paludiculture, biomass may be produced from vegetation which developed by succession after rewetting, or from cultivated stands of specific plants like common reed or cattail and can supply raw materials for the construction sector.

Building– and insulation products made from paludiculture plants in general require specific quality of biomass. Products obtained from paludiculture biomass include reed roofs and reed insulation boards, as well as cattail insulation boards and blown-in insulation, grass fibre insulation mats, cellulose foam boards and other board materials made from plant fibres. The plant components are used as a whole – e.g. the whole stalks in reed bundles for roofing or bonded reed insulation boards. Or they are shredded – e.g. to produce the Typhaboard, a construction panel made from cut and glued cattail leaves (Krus et al. 2023).

5.6.2 Common reed (Phragmites australis), natural growth or cultivation

(modified from Birr et al. 2021).

Reed produces high and stable yields on wet sites, even with long-term flooding. Reed is a flood– and salt-tolerant grass that grows up to four meters high and which culms remain upright after the growing season, making it suitable for harvesting in winter. Vegetative propagation results in the formation of large, competitive stands. Dead rhizomes and roots can contribute to renewed peat formation. Reed is traditionally used as a construction material and is also well suited for energy production.

What locations are suitable?

Degraded, rewetted fens with good nutrient supply are the optimal suited sites for the reed growth. In addition to good nutrient supply, permanent water levels at or above soil surface are necessary. Higher yields can be expected with a rewetting of up to 40 cm above soil surface. Slightly salty water is tolerated.

Are naturally established stocks eligible for utilisation?

Long-lived, naturally grown reeds are not suitable for intensive use in paludiculture. However, reeds can spontaneously appear on land after rewetting or can be specially grown and used. With natural vegetation development, common reed can colonize the rewetted sites, starting from remnant which have endured in ditches or wetter areas. This can take two to ten years after rewetting until the first harvest. It depends on the size of the area, the site characteristics and the size and number of reed occurrences, e.g. in the ditches, from where the species can spread. Once established, the reed stems can be used as permanent crops or as permanent grassland (especially spontaneously established, thinner stems).

What are the conditions of making the cultivation profitable?

Cultivation is an option if biomass should be produced quickly and safely meeting the quality

Common reed (Phragmites australis), spontaneous or cultivated

Water level:	(1) 10 to 0 cm in summer, 5 to 15 cm in winter (water level class 5+) or (2) 0 to 20 (40) cm above ground level in summer, 10 to 20 (40) cm above ground level in winter (water level class 6+)
Cultivation:	Planting, rhizome cuttings, stolon stalks or natural establishment after water level rise
Yield:	3,6 - 23,8 t TM ha^{-1} yr^{-1}
Harvest:	once a year, first harvest after 1-2-(3) years
Utilisation:	environmental-friendly building materials, bioenergy, raw material for lignin and cellulose production
Projected long-term emissions	7 t CO_2-eq. ha^{-1} yr^{-1} (soil moisture class 5+) 0 t CO_2-eq. ha^{-1} yr^{-1} (soil moisture class 6+ under GEST approach)

Photos 24 – 25.
Reed mowing with a Seiga-like harvester and transport of reed bundles after manual combing and bundling in Rozwarowo, Poland (Wichtmann 2006)

requirements for material use and thus covering the investment costs. After planting, it takes two to three years until the culms can be harvested. In order to meet the requirements for roofing, a longer time is usually needed. In general, reed is an unpretentious plant. It is important that water and nutrients are available or restorable to a high degree.

Nitrogen is usually the limiting nutrient for optimal growth conditions. A pH value below 4 has an unfavourable effect on the plant growth. Reed is also sensitive to accumulations of anaerobic degradation products (sulphides, ammonium, organic acids).

Which factors should be considered during cultivation?

The area should be mown before planting, the mown material removed and then the soil should be scarified. After planting, we recommend a short-term shallow rewetting to ensure good growth of the plants and to suppress emerging competitor species. During the first two years, the reed cultivation area should not be rewetted to high water level, only up to 5 cm above soil surface, as only larger contiguous reed stands with a fully developed rhizome system can tolerate higher water levels.

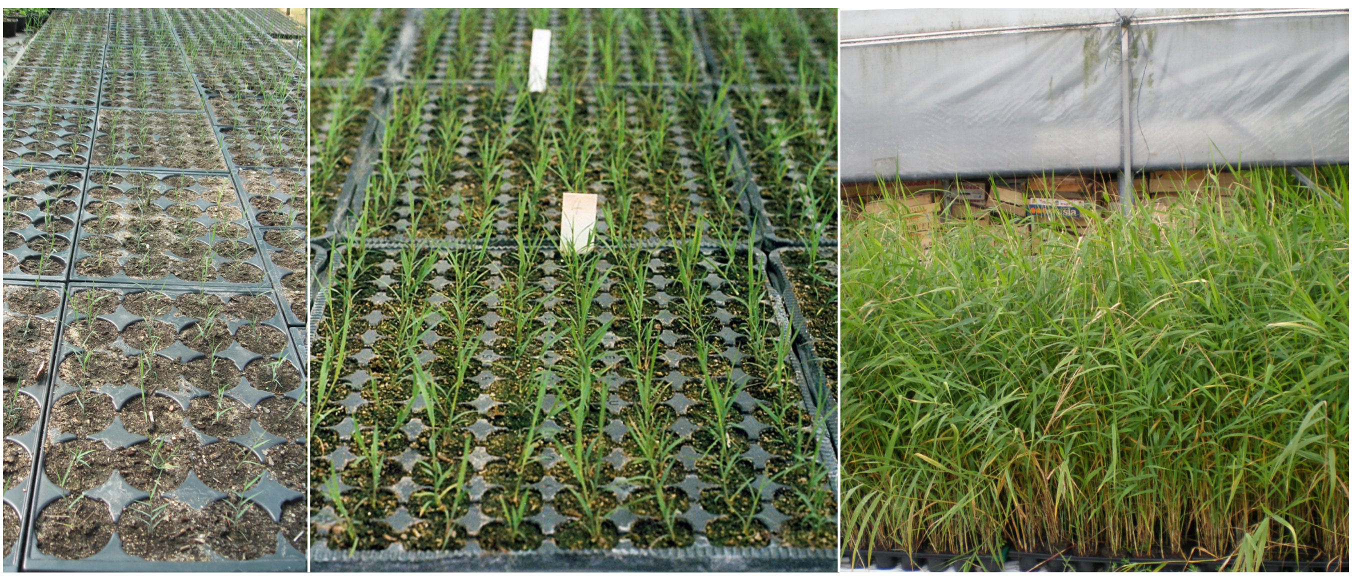
Seeding is also possible. However, the conditions for successful stem establishment have a limited optimum range: the seeds germinate only on wet soil, and flooding must be avoided. The seedlings are susceptible for drying out and need a constant water supply to compete with other plants due to slow growth. On the other hand, reeds established from rhizomes can tolerate temporary drought.

What planting material can be used?

Reed planting can be established with the seedlings grown from seeds, culm cuttings, rhizome cuttings or meristem propagation (generative tissue to gain genetically uniform plant material with identical characteristics). The most successful method is to grow seedlings from seeds in a greenhouse.

The seeds should be taken in winter from a population close to the cultivation area and comparable in location, after they have experienced a few days of frost for vernalisation. Stored in a dry place, they can germinate from one to four years. We recommend using the seeds of highly productive reed types only if the nutrient supply of the cultivated area is correspondingly high. It is also possible to sow the reed seeds directly into vegetation-free soil in late spring if the water levels are at field surface. Flooding needs to be avoided. In general, the establishment of pure reed beds by direct seeding is limited due to the slow growth of the seedlings, their sensitivity to flooding or drying out, and their low competitiveness with other grasses at the beginning.

There are genetically determined differences in the site requirements, which must be considered



Photos 26 – 28.
Different stages in preparation of seedlings of common reed for later planting in the field (Wichtmann 2008)

Photo 29.
Planting using a forest planting machine (Wichtmann 2008)

in the establishment of reed beds: different stem structures are achieved with comparable site conditions. The genetic variability leads to differences in stalk length, stalk density, dry matter and nitrogen content in the stems.

When is the right time for planting?

When the young plants have developed about ten culms that are at least 20 cm high, they can be planted out in the field. The planting period starts after the last night frosts in June and ends in August. Depending on the desired establishment period, the planting density could range between 0.25 and 4 plants per square metre. If water levels are low, planting can be done with conventional planters before rewetting starts.

The expected profitability

Depending on the location and genotype, a harvest in summer (August/September) of 6.5-23.8 t of dry matter ha^{-1} yr^{-1} and in winter of 3.6-15 t of dry matter ha^{-1} yr^{-1} can be expected. This corresponds to an energy yield (winter harvest) of 16-66.5 MWh ha^{-1} yr^{-1}, which could save 1,600-6,650 L ha^{-1} yr^{-1} heating oil equivalents. The productivity of reed depends primarily on the water availability. Annual reed mowing in winter – especially on nutrient-poor sites – can lead to a decrease in the yields. Due to the sufficient nutrient availability of rewetted peatlands, stable yields can be expected, at least over the first few years. Annual summer mowing reduces the vitality of the plants and can completely displace them.

What is the best time to harvest?

The harvesting time depends on the intended type of utilisation of the biomass or the type of utilisation must be selected according to the harvesting time. Up to now, reeds for roofing have mostly been harvested in sections in natural reedbeds annually in late winter between January and the end of February/mid-March with exceptional permits by nature protection agencies. By then, the culms are dry, nutrients are allocated to the rhizomes and most of the leaves have already fallen off. To avoid damage to the soil and plants, we should harvest when the ground is not yet frozen. In the case of reeds, annual mowing in winter can lead to a reduction in yields, especially on nutrient-poor sites. On rewetted lowland peatlands, however, sufficient nutrients are available so that annual winter mowing is possible. For the establishment of reed cultivation, which has so far only been tested as a pilot project, harvesting would also be necessary in other time periods, corresponding to the aims of stock management.

Photo 30.
Planting using a forest planting machine (Wichtmann 2008)

If harvesting aims at utilisation for the energy purpose (pellets, briquettes), it is carried out in winter, and should be done as late as possible. The water content decreases continuously from autumn to late winter, so that improved storability and higher heating and calorific values are achieved with a winter harvest. Mowing every two years additionally increases the suitability for combustion due to the proportion of old stalks, as they contain fewer combustion-critical elements (e.g. chlorine, nitrogen, sulphur) than the stalks from the current year.

For utilisation in a biogas plant, on the other hand, it makes sense to harvest as early as possible in the summer in order to achieve a higher gas yield. However, this weakens the competitive power of the reed and at the same time increases nutrient removal. Summer harvesting should only take place every 3-5 years so that the reed stands are not damaged too much. Sporadic summer mowing can improve the quality of the reed (e.g. improving the biometrics for roof reed). However, over several years, reed productivity will decline and other plant species (e.g. sedges) will take over.

What should be considered when mowing?

When harvesting reeds, a machine cutting height of at least 30 cm should be ensured, as stalks that are flooded after cutting will rot out and not sprout again. The cutting height should be based on local, annual water level fluctuations and take into account possible flooding events. Furthermore, if reed will be used for roofing, the cutting height should not be higher than 50-80 cm, otherwise the thatch will have low breaking strength. Information on harvesting techniques that can be used for harvesting reed can be found in Chapter 2.

What options for the material and products utilisation are available?

Traditionally, reed stalks are used as roofing and insulation material. Due to a steadily growing demand for ecological building materials, about 80% of the roof reed used in Germany is imported. More recent developments are the production of insulating plaster from reed fibres and fire protection panels from reed. Furthermore, reed represents an ideal raw material for lignin and cellulose production. Business models show that using biomass for production provides higher profitability compared to using it as an energy source.

For roofing material, a water content of not more than 18% is required. This could be normally achieved during a winter harvest. Only long, straight and flexible culms meet the requirements. Depending on the length of the culms (1.5-2.3 m), the diameter should be between 3-12 mm.

Reed fire protection panel is produced from the whole reed plant harvested in winter in combination with a mineral adhesive. Here, reed is a substitute for cereal or rape straw, as it has similar properties. The technology can be also used to produce other composite bodies. One of the manufacturers is, for example, Strohplattenwerk Müritz GmbH.

Egginger offers reed stucco as a plaster base (without insulating effect) for clay or lime plasters. Reed as an insulating plaster (insulating base coat and finishing plaster) has been developed in a project at the University of Greifswald, but has not yet been introduced to the market. Reed is also suitable as an aggregate for earthen building materials, such as reed clay building boards.

Hiss Reet (Bad Oldesloe, Germany) offers a wide range of reed products on the market. In addition to thatched roofs, building materials (thermal insulation, clay plasters), acoustic absorbers as well as reeds as privacy screens, for garden design and as sunshades are offered.

Which properties are necessary for utilisation?

In most cases, the harvested materials do not yet have the required properties for direct processing into products, so the final processing includes the conditioning of the biomass. In this way, the biomass is refined into homogeneous, reproducible batches that are then available for widespread use. Conditioning can be done by simple methods such as crushing, tearing, cutting, grinding and ensiling, or by combining individual steps.

What are the options for energy utilisation and what products are available?

Stalk-type biomass can also be used as raw material for the production of briquettes and pellets if harvested late in the winter. Compacting refines the raw material, improves its transportability and facilitates the use as fuel. If harvested early in summer, common reed can be used for a biogas plant. Well chopped and in small quantities, the biomass can be used in wet fermentation (fresh biomass or silage; see section 5.5.6). Solid-state fermentation (dry fermentation process) is also possible. Current research also shows that existing wet fermentation plants that already use grass as a substrate could convert to stalk material without losses. Furthermore, stalk-type biomass can be used for the production of plant charcoal through pyrolysis. As a rule, direct combustion is preferable to use in the biogas plant. Ultimately, the method of utilisation is determined by the capabilities of a particular company.

What is the implementation status?

For centuries, natural reed beds have been harvested and used for various purposes. However, the total area of reed thickets is declining. In Mecklenburg-Western Pomerania, for example, only about 550 ha of natural reed beds are still regularly used for production of thatch. Reed is not yet cultivated as an agricultural crop, mainly due to the current unfavourable funding legal framework. However, reed cultivation has been successfully established several times in pilot trials. Current reed cultivation projects are taking place in Bavaria (https://forschung.hswt.de/forschungsprojekt/958-mooruse) and Mecklenburg-Western Pomerania (https://www.moorwissen.de/prima).

How does the process affect the greenhouse gas emissions on the site?

Management of the wet peatlands with water level classes of 5+ and 6+ (in surface level to flooding) ensures a permanently water-saturated peat. This not only ensures peat preservation, but also peat formation, because reed is a peat forming plant. With the waters at soil surface, it is expected that reed will typically produce site emissions of ~7 t CO_2 equivalent ha^{-1} yr^{-1}. These consist mainly of methane (CH_4), a potent but short-lived greenhouse gas. At the higher water levels, the climate impact of CH_4 emissions is offset because CO_2 is removed from the atmosphere through the increased productivity of the reeds. For this reason, no site emissions are expected in the long term from areas that are also flooded in summer (~0 t CO_2 equivalent ha^{-1} yr^{-1}). In comparison, drained farmland on peatland emits more than 30 t CO_2 equivalent ha^{-1} yr^{-1}. In order to avoid strongly increased CH_4 emissions when reed beds are established, sudden rewetting with simultaneous high nutrient availability, e.g. through easily decomposable organic material, should be prevented. According to the current data, reed sites with permanent water levels above ground represent the most climate- and peatland-friendly management method of all the existing due to zero emissions.

How does this utilization method influence biodiversity?

Mowing with clearing limits the build-up of a “litter” layer in reed beds and increases the availability of light near the ground. Especially small and slow-growing plant species benefit from this, so that more heterogeneous and species-rich reed beds can develop compared to unused reed beds. This effect is more evident with summer mowing than with winter mowing. As a rule, this development is also associated with an increase in faunistic species diversity. Mainly, open land species and light– and heat-loving species that benefit from mowing. However, mowing also has an inhibitory effect on fauna through direct physical damage (injury/death). In addition, the removal of above-ground biomass restricts the development of shade-loving and litter-degrading species in particular. To mitigate the inhibitory effects, the use of biodiversity-friendly technology (e.g. oscillating instead of rotating mowers, high-cutting), the establishment of one-year rotating fallows, the biodiversity-promoting design of ditches (e.g. one-sided ditch maintenance) and the observance of adapted periods of use are recommended.

Costs and revenues

Reed can be used for energy production (combustion) or as material for roofing as plaster porter or as insulation material. Reed is only suitable to a limited extent for fermentation in biogas plants, as many biogas plants are not technically adapted to recycling. There is a high risk that the revenues will not cover the harvesting costs of reed material for the biogas plant (see Section 5.5.6). The highest revenues are achieved when reed is used as a building material. For details on funding, see (Närmann et al. 2021).

Table 6.
Costs and revenues for roof reed production per ha per year in an EU member state

Thatch (material)	Unfavourable scenario	Medium scenario	Favourable scenario
Costs	-769 €	-504 €	-838 €
Revenue	607 €	1.076 €	2.380 €
Profit	**-162 €**	**572 €**	**1.542 €**

How much does it cost to set up a reed bed in an EU member state?

According to literature data, cultivation of a reed bed in an EU member state will cost approximately 2,760 €/ha (Wichmann 2017). This includes the costs for planting material (5,000 plants/ha, 0.44 € per plant) and the labour costs. Annual harvesting is possible from the fourth year after planting. For a period of 30 years with 26 harvesting years, this results in an annual costs of €224 per year per ha. The costs and revenues from the Monte Carlo simulations by Wichmann (Wichmann 2017) are presented in the table, in which costs for the planting are not taken into account.

What costs and revenues can be expected for reeds used for roofing in an EU member state?

In the case of reed, 300 to 1,000 (500 on average) bundles are harvested per hectare. Harvesting, transportation and processing of the 100 bundles takes 2.4-4.7 (3.1 on average) working hours. Revenues of €1.9-2.5 (mean value: €2) are achieved per bundle. Special machines (Seiga and caterpillar technology) are required for harvesting of the reed. Dahms et al. (Dahms et al. 2017) have calculated the similar costs per average case: 554 €/ha with Seiga balloon tires and 527 €/ha with caterpillar-based chain technology.

The figures listed here are based on older surveys. They may only partially correspond to reality today, but are interesting to consider in terms of scale.

Production of thatch in Ukraine

Production of thatch material from common reed has a long tradition in Ukraine. After harvesting e.g. with Seiga-like machinery and transporting the reed to the factory premises, the primary bundles are stored in a barn for drying. Later the old culms and waste leaves from unwanted plants are combed out. This produces some 10 – 30% waste biomass, which is a good basis for producing pellets and energetic end use.

Pellet production from reed waste is reasonable, since the raw material costs almost nothing.

Case study: Production of thermal insulation plates in Ukraine

At Dnistrovets company in Maiaki, Odesa Oblast, located near the mouth of the Dniester, strong reed with a culm diameter larger than that of the reed used for the production of roofing material is used for the production of plates (2*1 m, ~5 cm thick).

One worker can produce 15 to 20 plates per day. Before the war, this company produced about 30,000 such plates per season. These plates can be used as insulation material but also can serve as plaster porter.

Modern use of reed in Ukraine.

Probably, the largest amount of wild reed was collected before the war in the floodplains of the Danube (Vylkove) and the Dnipro Rivers.

A representative of two brands, Solomo.house: Turnkey Straw Houses[10] and EcoBuildUkraine [11], reported that their company purchases reed bundles from the Danube Delta (they call it "sea reeds"). “Sea reed” culms are thinner, so there are more of them per bundle, which makes the bundle more

10 https://www.soloma.house/
11 https://eco-build.com.ua/

flexible, less brittle and more aesthetically pleasing. Therefore, they have to use "sea reed" for roofs with a "more complex design". The cost of one bundle is 2 EUROs.

The following offers of reed products exists now on the Ukrainian market:

DFB Elements company sells reed as a dried flower (the company specializes in the sale of dried flowers, stabilized plants and accessories) https://dfb.com.ua/product/ocheret-naturalnyj/

Reed fences made in China[12] and Ukraine[13] are available.

Reed beehives, reed beach umbrellas, reed plates and mates are offered. Two companies are producing reed straws for drinking: REEDS LLC and Reed Eco. Both companies have a full production cycle from collection to production. REEDS LLC also produces reed pellets and sells them through the Epicenter supermarket chain.

Ecopanel manufactures reed panels in Zhytomyr Oblast. The price indicated on the website starts from UAH 2,300 per m^2. They agree to try paludiculture reed under certain conditions.

12 https://prom.ua/ua/p766763143-zabor-kamysha-12m.html

13 https://www.olx.ua/d/uk/obyavlenie/ocheret-kamish-pleteniy-IDUdtXI.html

Photos 31-36.
From left to right, top to bottom: Drying of manufactured reed after processing (UkrReed, Ukraine) (Wichtmann 2017), combing and bundling of reed (Wichtmann 2017), reed pellet production line (BioTop, Reni, Ukraine) (Gaberl 2017), raw bundles waiting for further processing in a barn, biomass waste remaining after combing and bundling of reed, Ukrainian Danube delta (Wichtmann, 2017)


Photos 37-38.
Manual construction plates production at Dnistrovets company in Maiaki, Ukraine (Wichtmann 2017)

5.6.3 Cattails (Typha spec.), natural growth or in cultivation

(modified by (Birr et al. 2021)).

Cattails are suitable as a cultivation crop because they produce very high yields on rewetted sites with a high nutrient supply, even in the case of long-term overflooding, and, as expected, yields are stable over the first ten years. The high productivity of the plant in connection with the growing demand, especially for ecological building materials, offers versatile potential for creating the regional value.

A cattail stand developed after accidental rewetting of a peatland site near Kamp, Mecklenburg-Western Pomerania, Germany. After some years this stand dominated by Typha angustifolia was established and served researchers from Greifswald University as a site for scientific investigations (see Photos 39 – 42). Several different harvesting machines have been tested on this site.

Which sites are suitable?

Degraded, rewetted fens with a high nutrient supply and continuous water supply are optimally suited sites for cultivation. However, permanent water levels in or above soil surface are necessary. Cattails prove to be salt– and acid-tolerant and also thrive in brackish water. Due to their resistance to most herbicides, cattail beds in wet areas would also be effective as a buffer zone around water bodies in intensive agricultural landscapes as a nutrient and pollutant buffer (see Section 2.3). However, in this case the biomass will not suitable for many uses, especially not as building material, because pesticides can be accumu-

Cattail (Typha spec.), spontaneous or cultivated

Water level:	(1) 10 to 0 cm in summer, 5 to +15 cm in winter (water level class 5+) or (2) 0 to 20 (40) cm above ground level in summer, 10 to 20 (40) cm above ground level in winter (water level class 6+).
Cultivation:	Sowing, planting or self-seeding after the water level has been raised
Yield:	4,3-22,1 t of dry matter ha^{-1} yr^{-1}
Harvest:	Once a year in summer or winter (depending on utilisation); first harvest after 1-2 years
Area size:	Individual areas up to 10 ha
Requirements:	High nutrient and water availability, flat relief
Utilisation:	Ecological building materials, bioenergy, fodder, foodstuffs
Projected long-term emissions:	7 t CO_2-eq. ha^{-1} yr^{-1} (water level class 5+ under GEST approach) 6 t CO_2-eq. ha^{-1} yr^{-1} (water level class 6+ under GEST approach)

lated in the cattail. Due to the very good nutrient turnover, nutrient-polluted waters can also be directed through the area to serve as a fertilizer, so that cultivation in the vicinity of such receiving waters make sense. Thus, in addition to adding value via the biomass, the water filtering function of the plants could also be used to fulfil the requirements of environmental demands.

Are naturally established beds suitable for use?

Cattails can occur spontaneously on agricultural land after rewetting or can be specially cultivated. Both naturally established beds and planted crops can be used. With natural vegetation development, it can take two to ten years after rewetting until the first harvest. This depends on the area size, site characteristics and the size and number of cattail occurrences, e.g. in ditches, from where the species can spread. The seeds are carried into the target area by water or wind. Cattails can be promoted by neglecting ditch maintenance, which can further accelerate colonisation. In order to take full advantage of the spread via the waterway, hydrological management should be adjusted accordingly: ditch overtopping and interconnection of ditches in the catchment area are the best ways for the floating seeds to reach the target area.

In which cases cultivation is profitable?

Cultivation is a good option if biomass should be produced quickly and safely. After planting, it takes two to three years until the beds can be harvested with persistent yield. Long-term experience with the cultivation of cattails is not yet available, but the beds can probably be used as a permanent crop for at least ten years, provided a continuous supply of nutrients via nutrient-rich water can be guaranteed. In the case of a degradation of the sites with an accompanying decline in productivity, common reed spreads massively, so it could be expected that the area can continue to be used as a reed paludiculture site.

Which factors should be considered during cultivation?

The areas should be mown before planting, the mown material removed and the topsoil subsequently scarified. Short-term shallow rewetting (max. 5 cm) allows ideal germination conditions and exclusion of competing vegetation. In addition, the wet peat will be better protected from oxidation. The area should be divided into sub-areas (< 10 ha) with independently adjustable water levels in order to better regulate the uniform water levels. For even water levels,

Photos 39 – 42.
Cattail stand developed by natural succession near Kamp, Peene estuary, Germany. Cattail mowing with Seiga (right).
The photo below: Caterpillar-based technique. Big bales from Typha bundles. All photos by Wichtmann, 2018.

the height differences including the micro relief on the area should be as small as possible (≤ 20 cm). Topsoil removal may be necessary to compensate for height differences, but its extent should be kept as small as possible. At the same time, this could also provide material for an embankment that may delimit the sub-areas. The height of the embankment depends on the target water level and other functions of the area (e.g. flood protection). If the embankment needs to be passable, it may have to be made wider and more stable (e.g. of sand or gravel). It is important to have several access points for harvesting in order to minimise mechanical stress for the vegetation.

What planting material could be used?

Cattail is a perennial plant genus that is suitable as a permanent crop. Cattails can be planted with seedlings grown from seed or rhizome cuttings. Direct seeding can also be done. Planting enables a very fast bed establishment, but at the same time it is more cost-intensive. All native species of the cattail genus (especially Typha latifolia, T. angustifolia, T. x glauca) are highly productive and suitable for paludiculture. Broad-leaved cattail (Typha latifolia) is naturally more adjusted for surviving the dry periods than narrow-leaved cattail (T. angustifolia). In contrast, T. angustifolia tolerates high water levels in spring/summer up to 60 cm above ground. Typha x glauca is the sterile hybrid of the two mentioned cattail species and is similar to them in terms of site requirements and productivity. However, it tolerates a broader range of sites and at the same time tolerates both drought and overwatering.

Pre-grown young plants with a length of 25-50 cm and a well-developed root system are suitable for planting. The leaves can be shortened to 20-40 cm in length before planting to prevent additional evaporation – especially during warm, dry periods. Planting density of not more than two plants per m^2 is recommended. Trial protocols for the individual optimisation of planting at the respective site can be requested from the Radboud University Nijmegen: https://www.ru.nl/science/aquatic/research/research-lines/.

Rhizome cuttings are also suitable for planting. They are taken from natural stands and have the advantage to be planted as early as March. The precondition for planting is water levels a few cm below soil surface. Immediately after planting, the water level should be raised to 20 cm above soil surface. This promotes the development of the young plants and at the same time inhibits the emergence of the competing grasses.

With the less expensive direct sowing, ideal germination conditions are the water levels at or a few cm above ground level. Seed in the form of mature cobs is optimally obtained in winter (December-January) from natural beds, which are similar to those of the cultivated area in terms of water level and nutrient availability. One cob contains more than 100,000 seeds, of which over 80% have high germination potential.

When is the right time for planting?

The best time for sowing or planting is in the April-May-July period. Any gaps in the beds can be planted with early seedlings – a maximum of two plants per m^2 are necessary due to the rapid vegetative growth. Within one year, the number of shoots multiplies by 30 under optimal conditions. Smaller bed gaps should be left open to promote biodiversity. Conventional forestry or cabbage planting machines can be used for planting large-scale beds. Without adapting the technology, this only is applicable under the driest possible conditions, provided that the area can be rewetted afterwards. Otherwise, manual planting must be applied.

What should be considered during the vegetation?

Water and nutrients

Water levels should be easily to be regulated, as they have to be readjusted at least three times during a production cycle. While planting, the water level should be slightly below ground level, after planting 20 cm above ground level. Slightly higher water levels up to about 40 cm above soil surface are unproblematic, as well as temporal water level reductions. This requires good water availability in the early summer. For harvesting, the water level should be adjusted back to field level. After a possible summer mowing, inundation should be avoided, as otherwise further growth will be negatively affected.

Best growth performance is generally achieved with slight flooding (0-40 cm) and high nutrient availability. In rewetted, degraded fens, nutrients are usually sufficiently available, at least in the first few years, due to the mostly intensive previous agricultural use. The area can also be irrigated with water from nutrient-polluted receiving waters. The limiting nutrient for growth is mainly nitrogen, but also potassium and phosphorus. Water levels below ground level (< 10 cm) or drying phases should be avoided due to the emergence of other grasses and herbs. Shorter dry phases can be survived by the cattail largely undamaged, but the highly productive growth of the plants observed later is not good for their utilisation. pH values below 4 also limit the productivity of the plants.

Maintenance

At high water levels, there is hardly any accompanying flora; nevertheless, the marginal areas should be mown at least once a year, especially to suppress reeds (Phragmites australis). Any irrigation and drainage facilities (such as pumps, free inlets and outlets, etc.) must be regularly maintained. For young stands with low culm density and height, waterfowl can have a limiting effect on culms. As a countermeasure, water levels can be lowered to 0 to 10 cm below ground level for a few weeks, as waterfowl depend on flooded water during feeding. However, the measure would also promote accompanying flora that could inhibit cattail growth. The planting can also be covered with nets, which provides good protection against feeding by birds, e.g. from crows and white storks.

What is the best time for harvesting?

The harvesting time either depends on the intended type of utilisation of the biomass or the type of utilisation must be selected according to the harvesting time. The yield depends not only on the harvesting time but also on the water level and nutrient availability and ranges between 4.3-22.1 t of dry matter ha^{-1} yr^{-1}.

For material use as building and insulation material, harvesting takes place in winter (November to January). Winter harvest leads to a slight nutrient removal, although most of the nutrients are already stored in the rhizomes. For utilisation in a biogas plant, it makes sense to harvest as early as possible in summer in order to achieve a high gas yield. The same applies to use as fodder or if the aim is to skim off the nutrients. Here, harvesting must already take place in summer (July-August) – if necessary, a second cut in autumn/winter is also possible.

If harvesting is carried out in winter with the aim of energy production in the form of pellets or briquettes, it should be done as late as possible, e.g. at the end of February. Harvesting when the ground is frozen protects the soil and the rhizomes of the cattail. Cutting height between 10 and 20 cm preserves young shoots that can sprout again the next spring. The water level decreases continuously until winter, so that improves storability; higher heating and respectively calorific values are achieved. Mowing only every two years additionally increases the suitability for combustion due to the proportion of old culms, as they contain fewer combustion-critical elements than the culms from the current year. Nitrogen, sulphur and chlorine are those constituents that are significantly involved in corrosion processes of a combustion plant and in environmentally harmful emissions (e.g. NOx, SO2, HCl, dioxins, furans). Therefore, low contents of nitrogen (< 0.6% of dry matter), sulphur (< 0.2% of dry matter) and chlorine (< 0.1% of dry matter) should be aimed for in the biomass.

Harvesting requires the use of special technology due to the high-water levels (see Section 2). Depending on the use, chaff or the entire plant is harvested in bunches. For this purpose, the technique from reed mowing can be adapted.

What should be a harvesting cycle?

Cattail can be harvested annually with continuous nutrient supply (preferably from nutrient-loaded receiving waters) without a reduction in harvesting.

What should be considered during mowing?

The cutting height of cattails is between 10 and 20 cm. This allows the plants to sprout again. For persistent high yields and the maintenance of the permanent crop, it is generally necessary to harvest above the water table. Otherwise, water penetrates the rhizomes, roots and initiated anaerobic metabolic processes will lead to the death of the plant.

What material utilisation options and products are there?

Ecological construction materials

The material used for the biomass can achieve a higher added value compared to energy use. Due to its special properties, cattail biomass can be used as a multipurpose ecological construction material. It can be used as insulation material, e.g. blow-in insulation (see Photos 43, 44, 45) or insulation boards. In addition, a use as cattle feed for milk cows in interlactation periods has been tested [14]. Cattails (rhizome shoots) could also be used in human nutrition. Due to the low storage density, cattails should be processed as locally as possible in order to keep transport costs as their lowest. For material utilisation or storage of the biomass, air drying is necessary. Conventional hay drying plants can be used for this purpose.

Biomass from Typha can, after it has been dried, chopped and fibres are roughed up, can be used as blow-in insulation material. For that purpose, the whole cattail plants are shredded and defibred. A "blow in test" was done with a blowing in machine from Isofloc. First, the filling was tested on a model example with a transparent plastic glass panel (Photos 43, 44 and 45). (Update VIII-k (moorwissen.de)).

For the production of insulation boards, cut cattail leaves and stems are pressed in longitudinal alignment and joined with a mineral magnesite adhesive. At 0.035 W m-1 K-1, the boards have a thermal conductivity coefficient lower than wood by a factor of 4, making them a good insulation material. They are easy to handle and, in addition to the insulating effect, also have good load-bearing and fire protection properties. Several companies already produce and sell them on a small scale (Naporo or Typhatechnik).

An insulating material can be produced from the whole cattail plant by defibration. It is suitable for thermal insulation (winter), heat protection (summer), sound insulation and can be well installed in roof and wall constructions. With the cattail biomass of one hectare produced in one year, the roof surfaces of six single-family houses could be insulated, for example. The technology for production is available and has been tested (e.g. Hanffaser Uckermark eG). Egginger company produces a biofibre clay plaster in which cattail is used as a fibre aggregate in combination with clay, loam and quartz sand.

Fodder

The cattail harvested in early summer can be added as a fodder for dairy cattle. The nitrogen and therefore protein content is highest before the flowering in June. Cattail harvested in late summer is richer in crude fibre and can be used proportionally for dairy cows in the 2nd lactation period. The pollen harvested in summer is food for Mesostigmata (predatory mites useful in organic farming for pest control) and the basis for medicinal tea manufactured in China.

Food

The shoots of the cattail are edible for human nutrition (similar to bamboo shoots). Dried roots could be used for the production of a flour that could act as a supplement to grain flour for baking and as a thickening agent. After removing the outer leaves, young plants could be used in food as raw product or cooked like asparagus.

Wastewater treatment

Cattails can be used as pollutant accumulators in wastewater treatment. It efficiently removes pollutants in artificial or constructed wetlands or from contaminated soils. In a demonstration plot near Anklam, Mecklenburg-Western Pomerania, Germany, during a study, pesticides such as glyphosate and picloram were found in the plants. In such case, it is no longer possible to use the plants as insulation material or food, but they may be combusted for energy production.

Horticulture and floriculture

Use as raw substrate substitute for peat in horticultural substrates is currently under discussion. It is estimated that during production of insulation materials, 15% of the plant is waste, which could, for example, be mixed with peat moss biomass derived from peat moss cultivation. Dried inflorescences can be used in floristry for decorative purposes.

Which processing steps are necessary for material production chains?

In general, after harvesting, cattail contains much water (40 – 60%). The water content must be technically reduced to 15-20%. In most cases, the harvested crop does not possess the required properties for the direct processing into the products. Therefore, the biomass should be conditioned before final processing. During this stage, the biomass is refined into homogeneous reproducible

14 Mid-lactation from month 4 to 8 https://www.thecattlesite.com/articles/4248/manaqinq-cow-lactation-cycles/

Photos 43-45.
Demonstration of blow-in insulation application with a transparent wall model and in a cavity for the insulation of a building in Kamp, Western Pomerania, Germany (Wichtmann 2016).

batches that are available for further use. Conditioning can be done through the simple methods such as crushing, tearing, cutting, grinding and ensiling, or by combining the individual steps. For some uses, it may be necessary to separate the pistil from the rest of the plant.

What are the options for energy utilisation and what products are available?

Cattail biomass from late winter harvest can be used as raw material for the production of briquettes and pellets. Material harvested in summer can be added (proportionate) to fermentation substrates in biogas production. Mixtures in proportions of 20% or 40% reduces the gas yield by around 10% or 20% compared to maize silage. Well crushed and in small quantities, the early harvested biomass can be used in wet fermentation plants. In the case of sole utilisation, only solid fermentation (dry fermentation process) is suitable. Cattail biomass can also be used to produce biochar through pyrolysis.

Characteristics of cattail as a fuel

The table below (Table 7) shows combustion-relevant characteristics of cattail in comparison with reed, spruce wood and rye straw. The calorific value of cattail is only slightly lower than that of wood. As with many grass-type fuels, the ash content is relatively high. In Canada, 88% of the phosphorus could be recovered from the ash and reused as a fertiliser. Overall, due to its outstanding properties, the focus of cattail should be on material utilisation and energetic use for energy production should follow this (cascade use).

To what extend the combustion facilities should be adapted to the biomass?

Automatic ash discharge technology is required for larger plants, as the ash content of semi-solid fuels is above average. In addition, the composition of the ash must be taken into account: combustion-critical constituents are for example nitrogen, sulphur, potassium and chlorine

Table 7.
Comparison of combustion-relevant properties

Kind of biomass	Ash content [% DM content]	Calorific value [MJ/kg]	Volatile components [% water and ash free]
Spruce with bark	0.6	20.2	82.9
Cattail	3.7-6.7	18.2	-
Reed	4.3	18.5	69
Rye straw	4.8	18.5	76.4

content of the biomass. In any case, technology adapted to grass material should applicable for cattail, e.g. fluidised bed combustion or cigar combustion for baled biomass.

What is the status of the implementation of the procedure?

Cattail cultivation is not implemented on a farm level in Germany. From 1998 to 2001, a test cultivation took place on 6.2 ha in the Donaumoos within the framework of a DBU project. In Germany cattail is harvested for research trials from spontaneously established beds after rewetting of agriculturally used lands. Within the research project CINDERELLA (https://www.moor-wissen.de/de/paludikultur/projekte/cinderella/cinderella.php), in 2017, the targeted cultivation of various Typha species was tested in the Netherlands on a total of about three hectares in 5 areas (Zegveld, Zuiderveen, Bûtefjild, Deurnese, Peel). Additionally numerous small experimental plots had been set up in Mecklenburg-Western Pomerania for testing cultivation as permanent crop. Feeding trials with dairy cattle showed that cattail is proportionately suitable for feeding of cows in the interlactation period. In Manitoba (Canada), natural cattail reeds are being harvested on a pilot basis in the Lake Winnipeg catchment area for filtering nutrients and for the bioeconomy (production of biogas, ethanol and fibres, and recovery of nutrients). In Switzerland, cattails were used as a building material on a trial basis in 2007, and further cattail cultivation was tested in a project between 2009 and 2011. Current cattail cultivation projects are taking place in Bavaria in 2016-2022 (https://forschung.hswt.de/forschungsprojekt/958-mooruse) and in Mecklenburg-Western Pomerania in 2019-2022 (https://www.moorwissen.de/prima).

How does cattail cultivation affect the site's greenhouse gas emissions?

Wet fen management at wet water level classes of 5+ and 6+ (in surface level up to flooding) ensures a permanently water-saturated peat body, which ensures peat preservation. However, it has not yet been proven that cattails form peat in the Central Europe. At water levels in surface level, cattails are typically expected to produce site emissions of ~7 t CO_2 equivalent ha^{-1} yr^{-1}. These consist mainly of methane (CH_4), a potent but short-lived greenhouse gas. Even at higher water levels, these remain almost identical for cattails, while CO_2 emissions become slightly negative, i.e. CO_2 is removed from the atmosphere. Site emissions of ~6 t CO_2 equivalent ha^{-1} yr^{-1} can be expected for areas that are also flooded in summer. In comparison, drained farmland on peatland emits more than 30 t CO_2 equivalent ha^{-1} yr^{-1}. In order to prevent increasing CH_4 emissions when cattails plantations are established, sudden rewetting with simultaneous high nutrient availability, e.g. through easily decomposable organic material, should be avoided.

How does management influence biodiversity?

Only a few studies have been conducted on the effects of cattail cultivation and harvesting on the biodiversity of fens. However, it can be assumed that mowing with biomass removal limits the formation of a litter layer and increases the availability of light near the ground. Especially small and slow-growing plant species benefit from this, so that more heterogeneous and species-rich cattail reed beds can develop compared to unused ones. This effect is probably more pronounced with summer mowing than with winter mowing. As a rule, this development is also associated with an increase in faunistic species diversity. It is mainly open land species and light– and heat-loving species that benefit from mowing. However, mowing also has an inhibitory effect on fauna through direct physical damage (injury/death). In addition, the removal of above-ground biomass restricts the development of shade-loving and litter-degrading species in particular. The removal of the litter layer suppresses breeding bird species, such as the little crake or the reed warbler, through damaging of their nests. To mitigate the negative impact it is recommendable to, use biodiversity-friendly technology (e.g. oscillating instead of rotating mowers, high cutting), establish annual rotation of fallow sites, apply biodiversity-promoting ditch design (e.g. one-sided ditch maintenance), and to observe adapted management schemes for sensitive species.

Costs and revenues

The costs and revenues (per ha and per year) were taken from Schätzl et al. 2006. It is assumed that the plant costs are depreciated over 10 years. In 10 years, 8.6 harvests can be pro-

Table 8.
Costs and revenues for cattail cultivation per ha and per year (the calculations are made for Germany in 2021)

		Unfavourable case	Medium case	Favourable case
Costs	Depreciation of capital assets	-1.120 €	-680 €	-80 €
	Depreciation of the planting costs	-570 €	-570 €	-570 €
	Harvest	-1.600 €	-1.450 €	-1.200 €
	Maintenance	-1.040 €	-930 €	-810 €
	Total	-4.330 €	-3.630 €	-2.760 €
Revenue		2.106 €	3.537 €	5.400 €
Profit		**-2.224 €**	**-93 €**	**2.740 €**

duced. In the unfavourable case, cattails were cultivated on 4.7 ha, in the favourable case on 20 ha. The investment costs for the medium case were derived from these values. In the unfavourable case, minimum yields of 7.8 t DM/ha were calculated, in the favourable case maximum yields of 20 t DM/ha; and in the medium case yields of 13.1 t DM/ha (mean value from literature values). As cattail products are not yet established, there are no prices yet. Schätzl et al. (2006) have calculated that, at medium prices, at least 270 €/t DM of cattail (marketed as insulation material) must be achieved to cover costs. For further details on funding, see Närmann et al. 2021. Nevertheless, the figures listed here are based on older surveys. They may only partially correspond to reality today, but are interesting to consider in terms of scale.

Case study: Construction plates

Biomass from wet meadows can also be processed into building materials (e.g. construction panels) using more complex processing methods. The biomass is pressed out, defibred and thus modified mechanically, chemically or by applying heat and pressure in order to achieve the desired product requirements (Nordt and Wichtmann 2024).

Photos 46-48.
Left: leave (above) and stalk (below) of Typha and a construction board made from Typha (right)

Typha (cattail) in Ukraine

Other options for using cattails other than typha weaving[15] and as a plant for ponds have not been found.

The traditions of typha weaving in the villages of Shchitky and Pysarivka of the Vinnytsia Raion[16] of the Vinnytsia Oblast were included in the National List of Elements of the Intangible Cultural Heritage of Ukraine (Order of the Ministry of Culture and Information Policy of Ukraine dated 05.04.2023).

It is interesting how the plant was collected: "The harvesting of cattails, which was closely related to the natural cycles of the plant's development, began at the end of August, after the Transfiguration, and continued throughout September. They cut cattails, wading waist-deep in water, using sickles on a long stick to cut just above the root. Now cattails are cut with a knife in swampy areas. They dry the cattail in the sun, turning it over from time to time so that it dries out. Cut leaves are dried in the shade to preserve their green colour. Dried cattails are stored under cover, in attics".

Cattail weaving was also developed in other regions of Ukraine where cattails grow a lot, such as Baturyn[17].

5.7 Paludiculture for food

A promising outlook for the use of peatlands where topsoil has been removed or for depleted cutover peatlands after rewetting is berry cultivation: American cranberry Vaccinium macrocarpon, northern cranberry Vaccinium oxycoccos, bog bilberry Vaccinium uliginosum, and lingonberry Vaccinium vitisidaea. The central and northern areas of Ukraine are most favourable for the cultivation of American cranberry. Recommended sites are recently exhausted cutover bog and transitional peatlands with a peat layer of at least 30–50 cm and a medium acidic reaction (pH 3.0–5.5). It is also profitable to cultivate bog bilberries and lingonberries on depleted peatlands after certain restoration activities. There is positive experience in planting northern cranberries and bog bilberries in Belarus, e.g. in an experimental station of the National Academy of Sciences which is located in the Hantsevytskyi area. There are also several successful production sites for cultivating northern cranberries in various regions of Belarus under climatic conditions comparable to Ukrainian Polissia.

Case study: cranberries

Bart Crouwers runs a cranberry farm on wet peatlands in the Netherlands. Starting some years ago, he established this farm in the region between Amsterdam and Rotterdam, which was normally used for dairy cows grazing. The site is rather nutrient rich. Before spreading cranberry propagules, the grass sward topsoil (~15cm) was removed. Some mycorrhiza ericoides must be present so that cranberries can grow. Weeds develop in parallel with cranberries, but may be partly controlled by raised water tables, especially by full inundation during winter. In winter water tables should be like flooding, in summer -20 to -30 cm. Also the pH (<5) which establishes after rewetting and topsoil removal regulates the weeds. Some weed plants have to be controlled manually (buttercup) other by regular mowing at a height of about 20 cm above ground. Several varieties from America have been planted. At first, one year was necessary to propagate the plants. 4 plants have been spread per m², but in good conditions only 2-3 plants would be necessary for 1 m². The cuttings which had been prepared have at first been planted in April. Some yield already was obtained after 3 years, and in 2022, after 3-5 years, the cranberry cultivation was yielding handsome returns. The yield is about 50-60 T/8 ha. Additional incomes are received by emissions reduction certificates.

15 https://we.org.ua/kultura/rogozopletinnya/

16 https://uccs.org.ua/novyny/tradytsii-rohozopletinnia/

17 https://cheline.com.ua/news/society/traditsiyi-rogozopletinnya-v-baturini-foto-353726

Experts (Cherevko et al 2020) advise to grow niche crops in Ukraine, which include berries, medicinal plants and essential oil plants. Currently, the list of paludiculture plants includes 5 berries: northern highbush blueberry, American cranberry, small cranberry, European blueberry, and lingonberry.

Northern highbush blueberry

Northern highbush blueberry (Vaccinium corymbosum) is not native to Ukraine, but it is grown massively on the industrial plantations of the country, and currently Ukraine ranks eighth among the 10 leaders in terms of the area of blueberry plantations in Europe.

Northern highbush blueberry industrial crops in Ukraine will continue to grow, due to the fact that young plants have not reached their maximum productivity. The major part of the yield is exported. Over the past 5-7 years, the global price for the Northern highbush blueberries has remained at approximately the same level, but the cost of growing increases every year (Kukhina, 2023).

Cranberry

Ukraine ranks 9th in the world among cranberry exporters[18]. In contrast to Northern highbush blueberries, there is a steady demand for this berry from EU countries.

There are two types of cranberries on the international market. The first, l**arge-fruited cranberry** or American cranberry (Vaccinium macrocarpon) is used for the industrial plantations. In Ukraine, this species is not found in nature. All experiments with industrial cranberry plantations are conducted with large-fruited cranberries. The Belarusian experience in growing large-fruited cranberries may be interesting.

Small experimental plantations of various varieties of large-fruited cranberries were established on peatlands after the peat extraction near villages of Verbivka in Rivne Oblast and Sekun in Volyn Oblast (Konovalchuk et al 2013).

The second species is **small cranberry** (Vaccinium oxycoccos), which grows under natural conditions in Ukraine. There are no industrial small cranberry plantations in Ukraine. This berry is collected on living peat bogs. Taking into account the significant investments required to establish a large-fruited cranberry plantation, it is more appropriate to use natural mires for collecting small cranberries, which requires management planning of the peatland complex, raising awareness of the local population regarding the careful attitude to cranberry producing mires, etc. It is possible to consider the management of wild plantations on the example with European blueberries, where it is suggested to plant seedlings on the wild plant plantations, but here you need the advice of cranberry growing specialists.

Harvesting of small cranberries on peat mires is one of the management components in paludiculture and therefore can be considered in the project as one of the possible areas of work.

Small cranberry (Oxycoccus microcarpus) also grows in Ukraine, but it is enlisted in the Red Book of Ukraine, so we do not consider it.

European blueberry

European blueberry (Vaccinium myrtillus) grows not only on mires, so not all areas occupied by European blueberries can be considered as paludiculture areas. No information was found on industrial European blueberry plantations. Therefore, we believe that all European blueberries on the Ukrainian market are wild.

The zone of high density of European blueberries (up to 50% of the total biological reserves) covers

18 https://24tv.ua/business/yagidniy-biznes-ukrayini-yak-zaroblyati-viroshhuvanni-zhuravlini_n1768684

the northern and central regions of the Volyn, Rivne, and Zhytomyr Oblasts. European blueberry wild plantations in the southern regions of Volyn, Rivne, Zhytomyr, and northern Khmelnytskyi Oblasts are medium and low-yielding. The decrease in the productivity of the European blueberry in Polissia is in many cases a consequence of drainage of the forestry areas.

Berries are harvested on an industrial scale in the Volyn and Rivne Oblasts. Thus, in 2023 oblast councils agreed collection of 4,395 tons of the berries in Rivne Oblast, and 4,915 tons in Volyn Oblast[19]. In the same year, Volyn entrepreneurs and companies that harvest blueberries paid 1.1 million hryvnias in tax payments to the budgets[20].

In 2022, Ukrainian organic wild European blueberries entered the TOP-10 organic products exported from Ukraine and accounted for 25.3 million dollars[21]. Wild lingonberries, wild cranberries, and black rowan occupy the following positions after blueberry in organic berry exports. It is likely that the increased demand for berries is connected with the closure of the EU market for Belarus and the Russian Federation[22].

Forestry plays an important role in the blueberry business. They not only issue collection permits, but also act as procurement managers and processing facilities.

Studies of the natural resources of the species indicate that the stability of European blueberry populations in conditions of intense anthropogenic influence is quite high. Intensive trampling of thickets near settlements undermines the viability of populations only with 5-10 times soil compaction. Logging is the most dangerous activities for European blueberries. Plantations significantly damaged during logging do not actually recover – at best, their recovery takes up to 10 years[23]. There are two more studies on the impact of forest logging on wild European blueberry plantations and the impact of anthropogenic load on the productivity of wild blueberry plantations.

The technology for improving wild plantations deserves attention, which includes rejuvenating pruning, replenishment of thinned plantations by sowing seeds, planting bushes or stem cuttings[24]. The berries and the leaves of European blueberry are used in the pharmaceutical industry. The quantitative criterion for the quality of blueberry leaves is the content of flavonoids – not less than 0.8%. A conducted research has established that the content of flavonoids in wild plant samples is in the range of 1.14–1.86%, and in the vast majority of industrial batches, it varies in the range of 0.7–1.0% (Vronska 2018).

Lingonberry

No information was found on commercial plantations of lingonberry (Vaccinium vitis-idaea L.). However, Manevytske Forestry informs about the use of lingonberries and European blueberries, which grow under natural conditions, for the production of jam[25]. There is still no experience of lingonberry paludiculture plantations.

The productivity of lingonberry in natural forest conditions varies annually and is 50–200 kg/ha. On the plantations, the yield of berries reaches 20–100 centner/ha, depending on the growing conditions, cultivation techniques, plant variety and climatic conditions of the year.

In Ukraine, there is a branch association Ukrainian Berries, which unites all professional players of the fruit and berry market. Members of the association are legal entities and individuals – entrepreneurs who specialize in the cultivation and processing of berries and stone fruits, supply of planting material, cooperatives, non-governmental organizations, educational institutions and other representatives of the sector.

19 https://itvmg.com/news/limiti-na-zahotivlyu-chornitsi-vstanovili-na-rivnenshchini-87148

20 http://www.jagodnik.info/byudzhet-otrymav-1-miljon-gryven-vid-zboru-chornytsi-na-volyni/

21 http://www.jagodnik.info/chornytsya-uvijshla-do-najbilsh-eksportovanyh-organichnyh-tovariv/

22 https://aggeek.net/ru-blog/perspektivi-viroschuvannya-fruktiv-ta-yagid-perspektivni-kulturi-sposobi-pererobki-eksport

23 https://plants.land.kiev.ua/160.html

24 https://uapg.ua/blog/viroshhuvannya-chornici-tehnologiya-viroshhuvannya-chornici/

25 https://t1.ua/people/34723-lisivnyky-nashoho-lishospu-tse-komanda-profesionaliv-yakymy-mozhna-pyshatys.html

5.8 Animals and possible approaches for sustainable livestock in paludiculture

Livestock farming in paludiculture on rewetted peatlands to some extent negates the positive aspects of rewetting. After all, fertilizer application is prohibited on these areas. The large amount of faeces from animals grazing on peatlands can be considered a problem. Livestock management methods for swampy meadows are very limited. Dairy cows or robust cattle are not an option in most cases due to the low carrying capacity of the sward, problems with parasites such as liver fluke (Heckendorn and Frutschi 2014), the large lungworm (Dictyocaulus viviparus), hoof diseases (footrot, pododermatitis chronica verrucose) and poor pasture quality. Additionally, poisonous plants like ragwort (Jacobaea vulgaris), Syn: Senecio jacobaea; celery-leaved buttercup (Ranunculus sceleratus) and marsh horsetail (Equisetum palustre) can also pose a danger. We assume that these are the plant species that should also occur in rewetted peatlands in Ukraine.

Based on the above, in most cases livestock farming on wet peatlands is unproductive, but, under certain circumstances, the use of geese, ducks (Närmann et al. 2021) or grazing of water buffalo is possible (Sweers et al. 2014). But even these adapted species require slightly drained conditions with soil water classes of at least 4+ (see Table 1).

At the same time, there is some potential for animal husbandry on peatland sites which cannot be completely rewetted for objective reasons (insufficient water quantities, terrain features), but these practices cannot be considered paludiculture.

Photo 49.
Ragwort (Jacobaea vulgaris)
(https://images.wagwalkingweb.com/media/articles/horse/tansy-ragwort-poisoning/tansy-ragwort-poisoning.jpg)

If organic soils are used for grazing by ruminants, it is important to consider that these sites are among the selenium-poor areas. To ensure enough and comprehensive supply of minerals to the animals, they should always be offered salt for licking with mineral supplements or mineral lick buckets. Selenium deficiency leads to weak calves, lack of drinking, flu-like symptoms in young animals and poor fertility in adult animals.

However, this does not mean that there aren´t some possibilities for managing rewetted peatlands using livestock. However, this is more likely to be at certain periods: mainly in the short term in midsummer when water levels are around 25 cm below the surface or deeper. This means that some mineralisation of the peat body or slight peat decomposition (and, accordingly, greenhouse gas emissions) should be accepted.

Photo 50.
Celery-leaved buttercup (Ranunculus sceleratus)
(https://www.picturethisai.com/wiki-image/1080/153410987699994634.jpeg)

Photo 51.
Marsh horsetail (Equisetum palustre)
(Equisetum palustre / Sumpf-Schachtelhalm / Equisetaceae / Schachtelhalmgewächse (naturspaziergang.de))

- Grazing by „dry“ milk cattle; young cattle can temporarily be present in the rewetted peatland, soil moisture class 3+/4+/5+ (see Table 1),
- Haymaking for winter fodder / bedding material for straw replacement (soil moisture class 4+/5+),
- Grazing by ponies; deer, geese and ducks (soil moisture class 3+/4+: peat decomposing conditions),
- Moorland sheep („Moorschnucke“) and other sheep breeds grazing in raised bogs, soil moisture class 3+/4+.

However, this can only be implemented on a small scale and as a farm-specific solution and is more suitable for peatlands that technically cannot be sufficiently rewetted from a climate protection perspective.

5.8.1 Pasture with water buffalo
(modified from Birr et al. 2021)

Shallow, rewetted lowland peatlands and the transition areas from peatlands to mineral soil sites are well suited for water buffalo husbandry. As a rule, the grazing system used is standing pasture or mowing-stand pasture. Water buffaloes can be used for both meat and milk production. Here we shall review the keeping of suckler herds and their use as "landscape keepers" to keep moist and wet areas open while at the same time making economical profit.

Why are the water buffalos suitable for grazing on wet peatlands sites?

The water buffalo is adapted to water depressions and wet areas. Due to its hoof physiology, it copes well with very wet and soft soils (water levels 5-20 cm below ground level). It is more frugal than other cattle breeds to be able to utilise vegetation of lower forage quality (with high crude fibre content). Therefore, wet meadows and meadows resulting from succession after rewetting are also suitable. Preference is given to sweet grasses, including reeds (Phragmites australis), cattail (Typha spec.) and water mannagrass (Glyceria fluitans). Sour grasses such as thistles (Cirsium spec.), nettles (Urtica dioica) and docks (Rumex spec.) can be used for grazing on year-round pastures, especially in autumn and winter. Tree foliage, especially alder (Alnus glutinosa), grey willow and eared willow (Salix cinerea, S. aurita) are also eaten by buffalo. The buffalos also eat crowns of smaller

Pasture with water buffaloes

Water level:	10-20 cm below ground level in summer, 5-15 cm below ground level in winter (soil moisture class 4+); higher soil water levels are possible in some areas or in general (soil moisture class 5+).
Cultivation:	(Heterogeneous) wet meadows and reeds from the succession after rewetting
Yield:	840 g per day and a calf
Density:	0.8–1.5 Live Stock Units (LSU) CO2-eq. ha^{-1} yr^{-1}
Utilisation:	Meat, milk
Projected long-term emissions:	~8–12 t CO_2-eq. ha^{-1} yr^{-1} (soil moisture class 4+; GEST approach; see Section 1.4, Table 1)

Photos 52 and 53.
Left: Ukrainian buffalos and a riding herdsman on a summer dike in the Danube Delta;
Right: Buffaloes cooling down in a ditch in Ukrainian Danube delta area (both photos: Wichtmann 2017)

trees. This shows the landscape-forming potential of the water buffalo.

In addition, water buffaloes eat young shoots of herbaceous plants, such as yellow iris (Iris pseudacorus) and neophytes such as Japanese knotweed (Fallopia japonica), Himalayan balsam (Impatiens glandulifera) or giant hogweed (Heracleum mantegazzianum). The browsing of low-energy stands usually takes place after the recovery of higher-value growth. Despite the unclear effect of poisonous plants on the health of water buffaloes, caution is advised against poisonous plants such as marsh horsetail (Equisetum palustre), autumn crocus (Colchicum autumnale), celery-leaved buttercup (Ranunculus sceleratus), ragwort (Jacobaea vulgaris), water ragwort (J. aquatica), bittersweet nightshade (Solanum dulcamare) and water hemlock (Cicuta virosa). In Brandenburg, a pregnant water buffalo cow was fatally poisoned after eating the hay that contained marsh horsetail (toxins in the plant did not degrade).

Water buffalo characteristics for husbandry

Water buffaloes are robust cattle that are highly adaptable to different climatic and environmental conditions. They have a calm temperament. They can be used for landscape management. They live long and can be used for 15-20 years.

Fertility management appears to be challenging. Since the calving interval is relatively long (15-25 months) and it is difficult to detect the oestrus period, it is indispensable to have a stud bull in the herd. To avoid inbreeding, this bull should not remain in the herd for longer than two years. Artificial insemination is an option only for milking cows. The buffalo does not interbreed with domestic cattle, so joint grazing is also possible.

The mother cows are easy-calving and the calves are growing well. This is an advantage for the areas close to the settlements, because worries regarding the health of the cows and the calves are minimised. The gestation period of cows is about 11 months. Every three years, in average, each cow can give birth to two calves. Cows do not mate until they are three years old. The calves are usually fed with the milk of the mother and weaned after about 9-12 months. Adult cows reach a weight of 600-800 kg. The weight of adult bulls is a little bit higher and in average about 800-1,000 kg (Birr and Luthardt 2021).

What should be the grazing area?

The advantage of water buffaloes is their special suitability for very heterogeneous sites, both in terms of soil type and moisture as well as vegetation structures. However, they can also be kept on dry pastures like ordinary cattle, but then they need a place for wallow. Shallow and sandy bogs are more suitable than deep ones, as they are less prone to soil degradation and silting as a result of trampling. In addition, water buffaloes, unlike ordinary cattle, do not sink in peat soil if it has a thickness of less than 70 cm. The transition areas from peat to mineral soil are predestined for water buffalo husbandry. Grazing is only possible to a limited extent in the case of overwatering (not in the case of extensive flooding). When grazing on wet areas, a dry retreat area is always desirable. This allows the animals to react to changing moisture levels. Furthermore, a wallow should be provided for them at a suitable place. On areas with water levels close to the river, the animals usually create their own wallows. At least a double electric fence should be used for enclosure, also on the water side (river or lake).

What should be considered when keeping water buffaloes outdoors all year round?

Even though water buffaloes are particularly robust, protection from cold in winter and heat in summer is necessary. They should be provided with a pasture shelter on a sufficiently large dry site for protection against the cold. The area can also be artificially raised, e.g. with sand, its size depends on the number of animals kept. If necessary, adjacent dry areas must be leased or the animals must be kept on a separate winter pasture if only lowland peatlands are available for grazing. Furthermore, a frost-proof drinking water and supplementary feeding should be considered in winter. Water buffaloes protect themselves from extreme heat by wallowing in water and mud holes. Additional shade, e.g. larger trees, is recommended. Mineral buckets or lickstones ensure that the animals are supplied with vital trace elements.

With lower-quality plant stands, the selection space for the animals must be all the greater, which requires a lower stocking density. Depending on the favourability of the site and the management objective, the recommended stocking rate therefore varies from 0.8-1.5 livestock units ha^{-1}. Lower stocking rates are possible, but this does not fully exploit the potential of water buffaloes to maintain and shape the landscape. The grazing system used is conventionally called “standing pasture” or alternating between mowing and grazing. The areas can be generously dimensioned, whereby care must be taken for daily herd control (checking fitness, signs of disease, fresh water and electric fencing, to keep them tame).

In suckler herd buffalo husbandry, the herd is usually divided into three groups: a group of suckler cows with their calves and a mating bull, a group of heifers which should not mate to avoid the inbreeding, and a group of young bulls which are not to be used further for breeding on the farm.

Concentrate feed should not be added due to nutrient import into the area and to minimise feed costs. Supplementary feeds consist of hay. According to some farmers, this requires 4-6 round bales (200 – 250 kg) per animal during the winter months.

According to previous experience, separate wolf protection is not necessary, as the animals are able to defend themselves.

What aspects of buffalo health care need to be considered?

Water buffaloes are generally considered to be very robust and not very susceptible to disease. This is also due to the mostly extensive outdoor husbandry, which minimises health and behavioural problems that can occur during intensive indoor husbandry. Nevertheless, water buffaloes can potentially suffer from the same diseases as the cattle, including foot-and-mouth disease, Bovine Tuberculosis, Infectious Bovine Rhinotracheitis, Bovine Virus Diarrhoea/Mucosal Disease and parasites such as lungworms, roundworms and liver fluke. One advantage over cattle, however, is immunity to the most common diseases, especially babesiosis.

While using medication to treat parasitic worms, it should be noted that conventional drugs such as avermectins and their degradation products are toxic and are largely excreted in the faeces. Damage is caused mainly to manure-feeding insects, but also to water bodies if treated animals have access to them. To prevent resistance, treatment should be selective and not applied to the entire livestock. Animals treated with avermectins should be temporarily housed (2 weeks).

Annual blood sampling for the prevention of BHV1, brucellosis and leukosis is officially required for water buffaloes in Germany. The easiest way to do this is on the ear or tail in the treatment stall.

Hoofs are very hard and therefore hardly susceptible. Nevertheless, they should be checked regularly and treated if necessary.

When is water buffalo farming economically profitable?

The profitability of water buffalo husbandry depends on many factors, including the size of the area. Besides direct payments for the managed area and transfer payments for the maintenance services, the sales opportunities are decisive, which, in Germany, are currently limited to direct marketing or marketing of breeding animals (especially females). Year-round free-range husbandry is less costly in winter compared to indoor husbandry and thus about 25-30% cheaper. With given sales opportunities, a herd size of 30 animals is to be considered possible, as here an optimal utilisation of the stud bull input is given. Smaller herds require a proportionally higher stud fee. Assuming a stocking rate of 0.8-1.5 animal unit/ha, this results in a grazing area of about 30 ha (plus winter location and winter forage areas).

What are the advantages of the mown pasture system?

In the case of mown pasture, the area is occasionally mown in addition to pasture use. The stand resembles a pasture; there are clear differences to meadows. The higher frequency of use leads to a greater proportion of undergrass and an increased occurrence of tread-tolerant rosette plants. Regarding site-appropriate use of fens, only extensive mowing pasture is recommended.

In contrast to extensive meadow use, extensively used mown pastures offer the possibility of continuously providing water buffaloes with higher-quality fodder. This form of use offers higher economic efficiency due to low labour requirements and the possibility to use large areas. The management system also has a positive influence on individual animal performance and health. Continuous grazing at a stocking density of < 1.5 livestock units/ha and a grazing break in winter can develop a dense sward.

Where should animals be purchased?

Buying animals through IBF – International Buffalo Federation is associated with a higher degree of security with regard to the health and vitality of the animals. It is also possible to buy from existing water buffalo keepers in Ukraine (see below) or to import animals from traditional water buffalo countries such as Romania, Bulgaria, Hungary or Italy. In any case, the health status of the animals should be checked.

What must be considered when breeding?

In contrast to the breeding requirements for the beef cattle for the suckler cow husbandry method, the longer inter-calving periods must be considered for water buffaloes. Due to the low distribution of water buffaloes, only limited breeding material (bulls) is available, which is why the procurement of suitable animals should be considered in advance. The risk of inbreeding must always be taken into account through appropriate measures, such e.g. purchase of bulls from other breeding lines.

What is the recommended herd size?

20-30 animals correspond to a natural herd size of wild cattle and can also serve as a rule of thumb for a water buffalo herd. Furthermore, with a herd size of maximum 30 animals, a good mating performance of the bull can be expected.

How high are the profits?

The gains in animal live weight are strongly dependent on the feed quality and the selection index. On the Darß farm estate, an average weight gain for herd was 840 g per day was achieved on landscape conservation areas characterised by an average forage quality. In Chursdorf (Saxony, Germany) 1000 g in herd average per day are achieved on a good and dry site. Slaughter maturity is reached relatively late at an age of 20-30 months. The slaughter yield can be assumed to be 55% of the live weight. The high-quality meat is characterized by its good taste properties and its low cholesterol and fat content. Overall, the water buffalo has a good carcass quality. In addition, the cows provide nutritionally valuable milk with a fat content of over 8% and a high mineral content, which can be used for drinking, to produce whole milk products and cheeses and in cosmetics production. However, milk production would be difficult to imagine on wet land for practical reasons (time and labour requirements, udder hygiene, drift path length, lower forage quality) and is more of an option with separate herd parts on other sites.

What challenges arise during slaughtering?

Unsuitable or distant slaughterhouses are seen as a major problem by some water buffalo farmers. Slaughterhouses still lack the appropriate equipment for the water buffalo's thick skull (bolt gun – but this could be provided by the farmer themselves) and experience in cutting up the carcass. Long transport distances also lead to stress and strain, which not only affect animal welfare, but also lead to a limited maturing process of the meat, which has a negative impact on its quality.

In general, the nature and physique of the water buffalo require different slaughter and maintenance conditions. The optimal option would be to shoot the animals on pasture. The grazing shot requires good planning. According to German rules, it is necessary to notify the competent authority 24 hours in advance; a bullet trap and a good, experienced shooter are also necessary. The animal must be transported to an EU-certified slaughterhouse within 60 minutes. The absence of stress is reflected in better values of various meat quality parameters (tenderness, colour, water retention capacity). Ultimately, pasture shooting also serves as a positive selling point for meat from extensive free-range water buffalo. Other alternatives could be a slaughterhouse set up jointly by water buffalo farmers or the establishment of a mobile slaughter transporter.

What are the marketing channels?

Direct marketing (farm shop, on-line shop, farm restaurant) with good customer care and direct information exchange about husbandry conditions, nature conservation services related with water buffalo husbandry, and, if necessary, grazing is the most promising way to market water buffalo meat. The high tourist attractiveness of the region, for example, frequent visits to the Darß farm estate, also has a positive effect on sales. In order to be able to sell the less valuable cuts of meat, it is advisable to sell them separated and packaged or to process them into sausages and burgers. Furthermore, the retail trade or the catering industry can be good buyers – but the latter is subject to fluctuations. Online-based markets such as in Germany (besserfleisch.de, kaufnekuh.de or marktschwaermer.de) can also be an alternative. Preferably ecologically (chrome-free) tanned hides can be considered as a by-product.

Are there any certificates and what are their benefits?

Regional organic labels or regional brands can have a positive impact on local and regional marketing of products. Examples are international organic logos or regional logos of organic farming associations.

What is the effect of the process on the greenhouse gas emissions?

In the case of very wet fen management (wetter formations of soil moisture class 4+), site emissions of ~8 t CO_2 equivalent ha^{-1} yr^{-1} can be expected. If the area is not fully rewetted and (variable) wet areas occur on peat, site emissions are estimated to increase to ~12 t CO_2 equivalent ha^{-1} yr^{-1}. In comparison, drained farmland on peat emits more than 30 t CO_2 equivalent ha^{-1} yr^{-1}.

How does management affect biodiversity?

Low intensity grazing opens up high-growing and species-poor vegetation stands and creates a species– and structure-rich vegetation mosaic. The respective selective food preferences of the grazing animals play an important role. Water buffaloes prefer sweet grasses, so that sour grasses and herbaceous vegetation are grazed later in the year. Additional gaps for pioneer species are created by stepping stones at frequently used passages. Seed dispersal through the faeces and fur of grazing animals also takes place. The structurally rich vegetation mosaic creates a high diversity of habitats for fauna. Water buffaloes show a pronounced wallowing behaviour, which creates habitats for amphibians. Areas kept free of vegetation by trampling provide important feeding and breeding habitat for several bird species. However, trampling by grazing animals can also affect fauna (especially meadow birds).

Costs and revenues (the data are provided for Germany)

For cost estimation it was assumed that grazing takes place all year round with 30 animals on 30 ha (plus winter site and winter forage areas). The material costs include costs for winter and summer feed, concentrates, mineral feed, bedding and water. Other costs include the veterinarian, insurance, interest on labour, interest on capital, fees to the animal disease fund, and slaughter. In three years, each cow can give birth to an average of two calves. It is assumed that with 30 animals per year, 4 bulls are ready for slaughter and 4 heifers are sold in their second year of life. This means that on 1 ha of land 0.13 bulls and 0.13 heifers are marketed per year. The costs and revenues (in € per ha per year) were taken from Sweers et al. (2014).

The data in Table 9 have not been newly assessed for this compendium. They refer to the situation in Germany, more than 10 years ago. Therefore, assumptions for costs have to be

Table 9.
Costs and revenues (in € per ha per year) of water buffalo husbandry on wet lowland peatland sites in Germany in 2021

		Unfavourable scenario	Medium scenario	Favourable scenario
Costs	Labour costs	-149 €	-149 €	-149 €
	Machine costs	-181 €	-181 €	-181 €
	Material costs	-409 €	-409 €	-409 €
	Other costs	-182 €	-182 €	-182 €
	Total	-921 €	-921 €	-921 €
Revenues	Yield	689 €	949 €	1.079 €
	Subsidies for livestock	100 €	235 €	680 €
Profit		**-132 €**	**263 €**	**838 €**

considered carefully, especially in relation to calculation on other landuse types for rewetted peatlands. The incomes are composed by yields from selling meat based on different assumptions on prices for meat and different amounts of subsidies. In the most favourable case, the maximum proceeds were used – 5.44 €/kg meat (total meat quantity for all cases) – 55% from living animal weight, in the medium case – 4.79 €/kg, and the minimum price – 3.48 €/kg. For details on funding, see (Närmann et al. 2021).

Table 9 shows that only the favourable case of buffalo husbandry seems to be profitable, if subsidies and agroenvironmental payments are not available. If the buffaloes have to be sold on the free market instead of direct marketing, the calculations will not be favourable.

Buffaloes in Ukraine:

There are few buffalo farms in Ukraine. These farms produce a variety of products and may also be of interest when it comes to the use of paludiculture biomass.

1. Play Eco-farm in Khmelnytskyi Oblast produces milk, cheeses, butter and soap from buffalo milk, produces sausages from buffalo meat – 30 Asian buffaloes
2. Karpatskyi Buivil Buffalo Farm (Vynohradiv, Zakarpattia Oblast)

   The population of Carpathian buffaloes in Ukraine is being revived (there is a herd of almost 100 purebred Carpathian buffaloes). As of today, only about 200 of these animals remain within the entire territory of Ukraine. The farm produces soap, cheeses, yogurts, butter, milk, condensed milk.
3. "A Little Paradise" Eco-farm (https://www.facebook.com/ecoferma.rk/) (Horinchovo Village, Zakarpattia Oblast) – 50 Carpathian buffaloes[26]
4. TASBIO LLC (Rudnia Village, Kozelets Raion, Chernihiv Oblast) – buffalo breeding and production of food products from buffalo milk (currently 85 animals). The retention system is untethered on a deep litter with the possibility of walking.

   The farm is located within the Mizhrichenskyi Regional Landscape Park.
5. Buffalo Village (Vinnytsia Oblast) buys high quality livestock in Europe. "We strive to develop a farm that will raise quality animals, and for this purpose we use breeding stock".
6. Buffaloes on Yermakiv Island in the Danube Delta Facebook – 17 buffaloes[27].

5.8.2 Pasture with geese
(modified from (Birr et al. 2021)

When keeping geese (or ducks), a rotational grazing system should be used, in which one to two mowing cycles can be inserted. It is also worth keeping geese on poorer quality pasture, as geese can easily utilise green and fibrous feed with a low nutrient concentration. They are ready to graze from the very first days of their lives and provide tasty meat of high nutritional quality. The low level of production of goose meat in Germany (around 13%) and high consumer demand make extensive goose farming on moist sites attractive.

Which sites are suitable for extensive grazing with geese?

Moist peatland sites characterised by average summer water levels between 20-45 cm below ground level are suitable for keeping geese. Heterogeneous sites with wet hollows and drier, mineralised areas are also suitable for keeping geese. The grass stands are usually made up of sedge and reed stands in low-lying hollows. Wetter areas with average water levels of 5-20 cm below ground level would also be suitable for keeping geese, but there is no experience of this as yet.

26 Zakarpattia farming: how a buffalo farm works – AgroPortal.ua

27 Return of Species | Danube Delta (rewilding-danube-delta.com)

Pasture with geese

Water table:	20–45 cm below soil surface in summer, 15–35 cm in winter (soil moisture class 3+), partly or permanently higher water tables (soil moisture class 4+) are possible
Vegetation:	Moist pasture, species of moist conditions
Yield:	Grassland: up to 8 t ha^{-1} yr^{-1} Geese: Weight gain approximately 1 kg/month
Duration:	Long term goose fattening: 28–32 weeks
Area size:	0.8–1.5 LSU ha^{-1} yr^{-1}
Utilisation:	Meat, possibly goose feathers
Assessed long-term GHG emissions:	~16–19 t CO_2-eq. ha^{-1} yr^{-1} (soil moisture class 3+) ~8–12 t CO_2-eq. ha^{-1} yr^{-1} (soil moisture class 4+) after GEST-approach

Geese in the late or long term fattening period (pasture fattening with a long rearing period of 28-32 weeks) grow up almost exclusively on grassland and therefore on the farm's own feed. The following table (Table 10) shows a selection of suitable goose breeds that are suitable for long fattening on wet fenland.

These breeds are characterised by their robustness and resistance to weather conditions and are above all good grazing animals with low demands on feed quality. Nevertheless, the special characteristics of each individual breed must be taken into account. Their suitability for extensive farming on (very) wet fen grassland also depends on their weight and their breed-specific behaviour.

We fully assume that there are local breeds of geese in Ukraine that are adapted to growing on wet soils, but were not taken into account in this study.

Why are geese suitable for grassland management on fenland soils?

Due to their light build (7-8, maximum 10 kg) and the anatomical structure of the paddles with webbed feet, geese are suitable for the management of wet fenland sites. They are relatively undemanding in terms of forage, as long as there are sufficient moisture-tolerant sweet grasses (e.g. meadow grass, meadow fescue, white bentgrass, swathes, fresh shoots from common reed, meadow foxtail, reed canary grass) on the site. Herbs and legumes are also eaten. Sedges such as the marsh sedge (Carex acutiformis) are eaten if necessary by the undemanding Diepholz goose. On the other hand, older reeds (Phragmites australis), rushes (Juncus spec.), sharp-edged grasses such as lawn sedge (Deschampsia cespitosa) and herbs such as nettles (Urtica dioica), dock (Rumex spec.) or goose cinquefoil (Potentilla anserina) are avoided. The plants are browsed very deeply, which

Table 10:
Selection of goose breeds suitable for grazing and their characteristics for extensive fen management on wet sites

Breed	Weight, characteristics	Demands on climate/forage
Bohemian goose	Up to 5.5 kg, lively, down-to-earth, spirited, hardy	Grazing animal, good feed conversion, needs bathing opportunities
German laying goose	Up to 6.5 kg, down-to-earth	Good grazer, good feed conversion
Diepholz goose	Up to 6 kg, hardy	Least demanding on pasture (also eats sedges)
Emden goose	10–12 kg, good meat, high yield of quality feathers	Needs valuable forage grasses with high vigour
Leine-goose	5–7 kg, agile, fertile, prolific, hardy, natural brood	Weather-hardy, grazing goose with good marching ability
Pommern-goose	7–8 kg, good meat, high quality feathers	Can be kept on pastures with livestock, moderately demanding

Photo 54.
Geese keeping on a moist fen peatland site in Uckermark district (federal state of Brandenburg) (F. Birr 2018)

means that the area is heavily utilised. Geese are distinctly grazing animals which, due to the special anatomy of their digestive system, are able to feed almost exclusively on grasses and forage. In general, the animals are supplied with all essential nutrients on the land.

From what area size is extensive goose grazing economically viable?

Profitability depends on many factors, including the size of the area. Goose farming in Germany is currently profitable from around 1,000 animals as the main source of income. This requires at least 20 hectares of land. For part-time farming, flocks of between 100 and 300 animals with correspondingly smaller space requirements are recommended. Extensive grazing with geese is less labour– and cost-intensive than stall-bound goose fattening. Supplementary feeding is generally only required for breeding and final fattening. The veterinary and treatment costs for extensive goose breeds are lower due to their good adaptability to the climate and good robustness.

What should you look out for when buying and who should you buy from?

Once you have decided on a breed, it is advisable to contact similar farms that work with the same breed in order to clarify the strengths and weaknesses of the breed with them and to establish contacts with breeders. Careful planning of hatching and young stock purchases should also take into account the health care of the flock: the health status of the hatchery should be made available to you, or the hatchery should be officially certified.

What herd size and pasture management are recommended?

The top priority when choosing the herd size is animal-friendly and peatland-friendly husbandry. It depends on

- the site conditions (structure and size of the area, soil and vegetation conditions),
- ensuring the necessary animal control.

Larger herds can be divided into individual groups. This provides a better overview during daily animal inspections and helps to adapt to the size and structure of the available grazing areas. According to one farmer's experience, a good group size is between 100-350 animals. Rotational grazing can be used as a grazing system. The herd is rotated after about 7-10 days.

Which fattening method is recommended?

A distinction is made between three types of goose fattening: short, medium and long fattening. Although short fattening of 8-10 weeks utilises the high youth growth of goslings, the carcasses very often do not meet the requirements of the market. Medium fattening lasts around 16 weeks, in which the animals are kept indoors or on pasture and fed additional feed. This method is currently predominant in Germany. The meat of the animals is of good quality. In long fattening, the animals are kept for between 28-32 weeks. Compared to geese reared for short or medium fattening, their meat is characterised by better, species-typical flavour characteristics and low fat content. The slaughter date should be before sexual maturity, as otherwise the carcass weight decreases again and it becomes economically unprofitable to keep them too long. Long fattening is a good option for farmers who keep their cattle on extensive pastures and market them directly. Here, if the husbandry is optimised and sales markets are available, top sales proceeds can be achieved.

How are geese kept throughout the year?

The goslings are either purchased from a hatchery or come from the own hatchery or offspring. For the first four weeks, they are kept in the barn with rearing feed rich in protein, minerals and vitamins, so that the intensive juvenile growth of the geese is optimally utilised. Around 7 kg of rearing feed is required per animal in the first six weeks. From the second week onwards, the goslings are initially acclimatised to the pasture on an hourly basis. The earlier the start is, the more favourable the feed economy is.

In the late fattening period, depending on the weather, the goslings are moved onto the pasture around the end of May/beginning of June. Before this, the area is usually mown to produce winter feed so that the geese can utilise the fresh growth. They are reluctant to eat higher vegetation. The animals remain on the pasture for 4-5 months, depending on when they are marketed. In autumn and winter, when the growth of the area decreases, the geese are fed additional grain (e.g. oats) or root crops (sugar beet pulp, potato flakes). This is also the phase of the so-called final fattening, in which the animals develop a sufficient proportion of breast and haunch. This usually requires a stable or barn and around 250 g of additional feed per animal per day.

What needs to be considered in herd management?

The most important thing for the animals is permanent access to fresh water, e.g. with a drinking trough trolley. Tarpaulins stretched over the area or existing shrubs can be used as a source of shade. In general, and to make it easier to move the flock, an electric fence with a battery (2,000-4,000 volts) is required. If the minimum standards are observed, the electric fence is also recommended to protect the herd against foxes and wolves. Livestock guarding dogs can also be used, which also have a defence effect against birds of prey, ravens and crows. Pyrenean mountain dogs and Maremmano, for example, are well adapted to the Central European climate.

What relevant aspects need to be considered in terms of poultry care and health care?

Geese have low housing requirements and are resistant to many poultry diseases. Nevertheless, competent care of the animals is a basic requirement for keeping them in order to prevent diseases. If the animals are left to themselves for long periods of time, diseases may be recognised too late and any approach and veterinary care can become a problem. The geese should therefore be visited at least once a day to check for any health problems.

In principle, parasitological care of the animals should be tailored to the herd and location. If bathing facilities are covered with faeces, worm infections can spread quickly throughout the flock. In this case, deworming agents must be used. In the case of certified organic husbandry, where prophylactic antibiotic administration is not permitted, bathing facilities can be dispensed with. Dammed areas and ditches would create a suitable bathing opportunity, whereby the risk of infection would be lower due to the larger water surface. The ditches should be included in the fencing (risk of escape) and the slope must not be too steep. If the above-mentioned options cannot be realised, the animals should at least be provided with an open water site that allows them to dive their feathers.

What needs to be considered when managing the grazing area?

In order to prevent the spread of undesirable species such as creeping thistle, rushes, reeds or dock species encouraged by selective grazing, and to remove overhanging forage, mowing should be carried out. Timely cutting can also prevent unwanted species from seeding. Rolling is not necessary on goose pastures.

In addition to the aforementioned species with inferior feed value, particular attention must be paid to the spread of poisonous herbs such as ragwort and water ragwort. The poisonous effect of other plants on geese is unclear. However, poisonous plants are generally avoided and not eaten by the poultry.

What are the advantages of the mown pasture system?

With mowed pasture, the area is occasionally mowed in addition to being used as pasture. In this case, the crop resembles a pasture; there are clear differences to meadows. The higher frequency of utilisation leads to a greater proportion of undergrowth and an increased occurrence of rosette plants that are tolerant of trampling. The cutting/grazing sequence depends on the forage growth. It is mowed once or twice during the vegetation period (mowing before emergence and re-mowing in autumn), with the focus of use being on grazing. With a view to proper fen utilisation, only extensive mowing is recommended.

In contrast to extensive meadow utilisation, extensively used mown pastures offer the possibility of obtaining additional hay or silage from the grazed areas. This form of use offers high economic efficiency due to low labour requirements and the possibility of large-scale use. This form of husbandry also has a positive influence on individual animal performance and health. Continuous grazing with a stocking density of up to 1.5 LSU/ha (equivalent to around 170 geese) and a grazing break in winter can lead to the development of a dense sward.

How high are the growth rates?

The live weight gain rates for female geese are slightly lower than for male geese. In general, the animals gain about one kilo of live weight per month, so that they can reach a maximum live weight of 10 kg at the time of slaughter, depending on the breed. The slaughter weight corresponds to around 70% of the live weight.

What influence do slaughter date, cold chain and maturing have on the quality of the meat?

Movement is particularly beneficial for meat quality. Bluish-coloured legs are a sign of quality, as their fat content is low due to the movement. The freshly slaughtered animals, including offal, are vacuum-packed and frozen. They are ready to eat straight away without going through a maturing process. Preservation by freezing has no negative effect on the quality of the meat.

What is the best way to market the goose meat produced?

In Germany, long-fattened geese are mainly marketed via direct marketing. There are still good marketing opportunities for organically produced goose meat via specialised organic butchers and the organic food trade.

The feathers of the geese can be used as an additional benefit. A goose that is 30 weeks old provides around 150 g of feathers and 70 g of down. The down is obtained by plucking during slaughter. Dry-plucked animals are valued at the highest price due to the integrity of the epidermis (the protective layer overlying the skin) and also have a longer shelf life when fresh. However, the time required compared to wet-plucked animals is higher.

What effect does the process have on the site's greenhouse gas emissions?

When geese are kept at groundwater levels between 15-45 cm below the surface (soil water level 3+), the upper peat body is permanently aerated. This promotes oxygen-dependent decomposition processes, bog subsidence and shrinkage and causes site emissions of ~16-19 tonnes of CO_2 equivalent ha^{-1} yr^{-1}. If geese are kept at higher water levels between 5-20 cm below the surface (water level 4+), site emissions of ~8-12 t CO_2– ha^{-1} yr^{-1} can be expected. The exact emission value depends on the actual water level and the vegetation. In comparison, drained arable land on peatland emits over 30 tonnes of CO_2 equivalent ha^{-1} yr^{-1}. Grazing with geese is a low peat-consuming process, which is why goose farming only makes sense from a climate protection perspective for (partial) areas where a near-natural water level cannot be fully restored.

How does goose farming affect biodiversity?

No detailed studies have yet been carried out on the effects of goose farming on biodiversity. The grazing of geese presumably leads to short-grass vegetation stands, from which grassland herbs in particular benefit. Gaps for pioneer species such as goose cinquefoil (Potentilla anserina) can be created by trampling damage at passing points. Light-loving animal species benefit from the short vegetation stands. Due to the geese's purely plant-based diet, it is unlikely

Table 11.
Costs and revenues of free-range goose farming per hectare per year in Germany

		Unfavourable scenario	Medium scenario	Favourable scenario
Costs	Free-range farming	-1.227 €	-821 €	-550 €
	Variable costs	-1.019 €	-1.019 €	-1.019 €
	Total	**-2.246 €**	**-1.840 €**	**-1.569 €**
Revenues	Yield	1.982 €	1.982 €	1.982 €
	Subsidies	100 €	200 €	680 €
Profit		**-164 €**	**342 €**	**1.094 €**

that they will hunt insects, for example. It is unknown whether the geese that are kept develop territorial behaviour and thus limit their suitability as breeding and resting grounds for wild bird species. To increase structural diversity, annual rotational fallows can be used by cutting them out during mowing and then fencing them off. When mowing, the use of biodiversity-friendly technology (e.g. high cut, oscillating instead of rotating mowers) is recommended.

Costs and revenues

In this case, all economic estimations are German experiences and may be rather different elsewhere, e.g. in Ukraine. The figures for the examples have been produced several years ago and nowadays these data may differ strongly in comparison to current situation. The costs and revenues for conditions in Germany, revenues and profits are given in relation to 1 ha of farmed land per year. However, it is assumed that a thousand animals are kept on a total of approximately 20 ha of wet (mown) pasture on portion pastures of 1 ha in size. In the favourable case, 3 groups of approximately 330 animals are kept (stocking density 2.772 LSU/ha), in the medium case 4 groups (approx. 2.1 LSU/ha) and in the unfavourable case 6 groups of approximately 170 animals (stocking density 1.5 LSU/ha). Carcass marketing is assumed, with an animal loss of 4%, a live weight of 6.6 kg, a carcass weight of 4.8 kg and a price of €8.60 per kg carcass weight.

Duck and goose farming in Ukraine

Over the past four years, the industrial population of geese has decreased by 90%, ducks by 10%. These types of poultry are mainly kept in households, however, there was also a 25% reduction in the population[28].

There is an interesting experience of the “Syla Zhyttia” (“Vital Power”) farm (Rivne Oblast), which is engaged in raising geese. The owner believes that “80% of geese feel good when fed on pastures and only with feeding once a day with waste from feed production”[29].

Trademarks selling ducks in Ukraine:

An online store Dychyna Delicacies offers free-range ducks, TM Vilna https://dychyna.com/. You need to order duck meat in advance. The preparation time can take up to 2 days.

Pyriatynsky Filvarok poultry breeding farm (city of Pyriatyn, Poltava Oblast) was established in 2008. Ducks of the Ukrainian Gray breed "in environmentally friendly natural conditions"[30] and geese are also raised. They are sold through https://thelavka.com/.

The company indicates that it sells natural duck meat (this is a scarce product, because it is associated with a natural diet and, accordingly, with an increase in the growth period of ducklings).

28 https://agrotimes.ua/article/ptahivnycztvo-u-prioryteti/ , https://agrotimes.ua/interview/za-pidsumkamy-roku/
29 https://agrotimes.ua/elevator/viroshchuvannya-
30 https://thelavka.com/dostavka-produktov-ptichya-ferma-piryatinskij-filvarok.html

Korobivskyi PPZ STOV Korobivskyi poultry breeding plant (Kedyna Hora Village, Cherkasy Oblast) is a large player in the duck meat market in Ukraine. It has the full production cycle: keeps parent stock, incubates eggs, grows young and commercial poultry. The finished meat products are sold under the Delicious Duck trademark in the supermarket chains throughout Ukraine. They sell Peking and Mulard ducklings.

Mulard is suitable for farms and homesteads. The company buys domestic mulards and geese from farmers, slaughters and sells them. Company owns the specialized transport for the delivery of livestock to the enterprise[31].

Companies engaged in breeding geese:

Agrolife Invest LLC – Town of Bakhmach, Bakhmach Raion, Chernihiv Oblast. Ukraine – T LLC – Trostianets Urban Settlement, Trostianets Raion, Vinnytsia Oblast. Promin PSP – Trybusivka village, Pishchanka Raion, Vinnytsia Oblast.

Potential stakeholders:

Non-Governmental Union "Interregional Union of Poultry Breeders and Fodder Producers of Ukraine" http://ptahokorm-union.com/

The online "Poultry Service Center" operates on the basis of the State Poultry Research Station of the National Academy of Sciences in the framework of cooperation with the Non-Governmental Organization "Interregional Union of Poultry and Feed Producers of Ukraine".

The "Poultry School" training club provided a cycle of educational seminars on the safe production of poultry products using the main types of poultry, including "Fundamentals of rational fattening of geese in farms and homesteads", "Fundamentals of rational fattening of ducks in farms and homestead farms".

There are specialists in breeding geese and ducks https://info.avianua.com/contact.php?id=76

5.8.3 Sheep grazing

(modified from (Birr et al. 2021))

Hardy sheep are in principle suitable for the extensive management of moist lowland grassland. The grazing is organised as rotational grazing or herding, or there is shepherding. Mowing pastures are presented as a variant of pasture use, on which occasional mowing takes place.

Photo 55.
Hardy breed Skudde on a damp lowland peatland nearby Schwerin (Mecklenburg-Western Pomerania, Germany; Photo: Birr 2018)

Which sheep breeds are suitable for extensive grazing of moist peatlands sites?

Sheep grazing

Water level:	20-45 cm below ground level in summer, 15-35 cm below ground level in winter (soil moisture class 3+); higher water levels possible in winter
Cultivation:	Mixture of wet meadow and wet pasture species
Yield:	Growth varies according to breed
Stocking density:	0.8–1.5 Live Stock Unit (LSU) ha^{-1}
Utilisation:	Meat, wool (milk)
Projected long-term GHG emissions:	~16–19 t CO_2-eq. ha^{-1} yr^{-1} (assessment by GEST approach)
Assessment of long-term GHG emissions:	~16–19 t CO_2-eq. ha^{-1} yr^{-1} (soil moisture class 3+) ~8–12 t CO_2-eq. ha^{-1} yr^{-1} (soil moisture class 4+) following GEST approach

31 http://www.duck.com.ua/articles.html

Sheep can generally be used for grazing on the moist grasslands, i.e. at water levels averaging 15-45 cm below ground level, although there are breeds that are particularly adapted to moist conditions. They are less susceptible to diseases caused by soil moisture than intensive breeds. In addition, they have fewer forage demands. Because of the selective feeding pattern of sheep, they are kept in rotational grazing or pasture. Sheep like to eat numerous plant species typical of wetlands or peatlands, such as wood clubrush (Scirpus sylvatica), meadow foxtail (Alopecurus pratensis), woodland figwort (Scrophularia nodosa), common reed (Phragmites australis), carpet bentgrass (Agrostis stolonifera), sedges (Carex spec.), purple moor-grass (Molinia caerulea) and sheathed cottonsedge (Eriophorum vaginatum), as well as emerging woody plants such as birch, quaking aspen and alder.

The following table gives an overview of the sheep breeds suitable for husbandry and landscape management on wetland sites. Each sheep breed is adapted to the regional climatic conditions due to the long history of use, which is why the regionally suitable sheep breeds should be used if possible. In addition, the special features of each individual breed must be considered. Their suitability for extensive husbandry on moist fens also depends on their weight and their breed-specific behaviour.

We assume that there are local breeds of sheep in Ukraine that are adapted to growing on wet soils, but were not taken into account in this study.

From what area size is extensive sheep farming economically profitable?

Profitability depends on many factors and is not of a primary function of area size. Economic success in sheep farming mainly depends on the following:

- level of lambing revenues (seasonal price fluctuations) and processed goods,
- availability of cheap fodder and efforts to keep the flock healthy,
- short stabling periods in the buildings that are as cheap as possible,
- good market conditions for meat and wool.

On what should we look when purchasing or from whom should we buy?

Once the decision for a breed has been made, it is recommended to contact a farm that works with the same breed in order to establish direct contacts with breeders[32]. It is also possible to contact a sheep breeding association directly, if any.

What is the recommended flock size?

A stocking rate of 0.8 to 1.5 LSU ha^{-1} is recommended for humid sites and extensive husbandry conditions. In the case of productive growth (reeds, reed beds, tall forbs), short, 1-2 week in-

Table 12.
Selection of hardy sheep breeds and their characteristics for extensive fen management of moist sites, modified from Nitsche & Nitsche (1994), Sambraus (2001).

Sheep breed	Weight, Characteristics	Products	Demands on climate and food
Bentheimer Landschaf	70-90 kg, hard hooves, resistant to mildew, capable of marching, hornless, good maternal traits; Semi-extensive breed	Meat	Resistant, undemanding
Cameroon Dwarf	30-50 kg, hair coat, resistant to sheep fly, all-season oestrus, sensitive to cold (stable/ shelter in winter); Extensive breed	Meat	Hardy, undemanding
White Polled Heath	40-75 kg, firm hooves, very mobile, hornless, seasonal breeding, lambing score 110 % (i.e. 110 lambs per 100 females); Extensive breed	Meat, Wool	Well adapted to vegetation and soil conditions of peatlands
Pomeranian Coarsewool	50-75 kg, good resistance to worm disease and mildew, lambing score 130 %; Semi-extensive breed	Meat, Wool	Well adapted to vegetation of bogs and unfavourable weather conditions
Deutsche Schwarzköpfiges Fleischschaf	70-135 kg, precocious, seasonal reproduction with long breeding season, hornless, lambing score 120-170 %; Intensive breed	Meat, Wool	More intense meat breed
Skudde	40-55 kg, hard hooves, lively, peaceful, all-season mating, lambing score 130 %; Extensive breed	Meat, Wool	Hardy, undemanding, good forager on poor growth

32 For example, Shepherds' Association NGO, head: Vasyl Vasyliovych Stefurak.

tensive grazing with 10 LSU ha^{-1} is also possible. However, these habitats can only be grazed with adapted landraces (e.g. white polled heath).

What should be considered in flock management?

The night stand should be located in a dry area away from vegetation of conservation value, as far as more faeces are released during the rest. Since droppings are also increasingly secreted at the beginning of the grazing period, the resting place should be at least 100 m away from the grazing area. In the case of paddock management, the resting place (shelter/windbreak with salt lick) should also be offered away from floristically valuable areas.

A one– to two-term mowing can be inserted into the grazing cycle (mid-June and September). This hay can then be used as winter fodder, whereby a high proportion of sedges and rushes from marginal areas of moors can also be utilised.

During the winter months, housing covers a period of 90-180 days, depending on the region and the type of housing. The sheep have low requirements for the barn, but it should be draught-free and dry. The most common type of housing is the deep run barn with bedding and without special thermal insulation.

How should the flock be secured against wolves?

Separate measures should be taken to secure the flock against the wolves. Advice on how to secure the flock and what to do in case of damage can be obtained from experts.

What are the relevant aspects of care and preventive health care?

The competent care of the animals is a basic prerequisite. Animal observation is indispensable to interpret conspicuous behaviour during rest and in motion. The assessment of excretions and the condition of individual body parts including hoofs and mucous membranes is crucial.

Signs of unwellness are drooping ears, often in combination with apathetic behaviour. Further indications can be: segregation from the herd, pale oral mucosa, bloody faeces or urine, loss of wool, increased body temperature, unwillingness to eat, no ruminating activity and absent rumen sounds. Respiratory diseases can be recognised by clearly strained or irregular breathing. In case of any of these signs, urgent action is required. In principle, parasitological care of the animals is necessary depending on the herd and the location. The most common internal parasite for ruminants on wetland sites is the liver fluke. If the animals graze on soft and moist soils, regular hoof monitoring and care is necessary. Moist sites can be the source of hoof diseases. For sheep, prevention of hoof rot (paronychia contagiosa) is of particular importance, which includes veterinary examination at least once every 2 months, cleaning the hooves of all animals in the flock at least once every 10 days, etc.

What should be considered in the management of the pasture?

Pasture management should be in portion or rotational grazing according to the motto "short grazing period – long rest period". Standing pastures should be avoided, not least because of the higher risk of infection with endoparasites. Winter grazing is mainly found in climatically favoured regions, such as southern Germany as part of traditional transhumance. Here, the felt layer of the overhanging grass is removed by the sheep flock, which favours the growth of meadow plants in spring.

In order to prevent the spread of undesirable species such as tussock grass (Deschampsia caespitosa), rushes (Juncus spp.), thistle (Cirsium spp.) or dock species (Rumex spp.) promoted by selective grazing, as well as to remove overstaying fodder, a post-mowing flailing and mulching should be carried out. This simultaneously suppresses the emergence of woody plants such as willows and alders as well as the seeding of the undesirable species. Alternatively, to control the above-mentioned species, which can be an indication of undergrazing, the stocking density can be increased or the animals can be allowed longer feeding times in the paddock. Overgrazing, on the other hand, is indicated by an increase in tread-resistant species such as creeping bentgrass (Agrostis stolonifera), broad plantain (Plantago major) or common silverweed (Potentilla anserina), which should be responded to with lower stocking rates or longer rest periods. Soil layers frozen after winter are pressed down again by rolling or by an early pre-grazing by the sheep flock. At the same time, the tillering of the grasses is promoted, which ensures good sward density. In contrast, currying for aeration and de-felting of the sward can be dispensed with.

As potassium is often a limiting factor for plant growth in poorly drained, i.e. still mineralising fens, it is advisable to distribute the excrements of the grazing animals by means of meadow drag or to constantly change the winter-feeding sites. The feeding points can optionally be covered to bind the excrements in the litter. The resulting manure can then be distributed on the land again.

In addition to the above-mentioned species with inferior feed value, attention must be paid to the spread of poisonous plants such as swamp horsetail (Equisetum palustris), bittersweet nightshade (Solanum dulcamara), water ragwort (Jacobaea aquatica) and, on drier sites, common ragwort (Jacobaea vulgaris), common buttercup (Ranunculus acris), autumn crocus (Colchicum autumnale) and water hemlock (Cicuta virosa). These plant species can be controlled or suppressed by an appropriate mowing system or by weeding out.

What are the advantages of the mown pasture system?

The area of a mowed pasture is occasionally mown in. In this case, the stand resembles a pasture, and there are clear differences with the meadows. The higher frequency of mowing leads to a greater proportion of undergrass and an increased occurrence of tread-tolerant rosette plants. The sequence of cutting and grazing depends on the vegetation growth. Mowing is conducted once or twice during the vegetation period, with the focus on grazing. We recommend only extensive mowing for fenlands.

In contrast to extensive meadow use, mown pastures offer the possibility of continuous provision of a higher-quality fodder for the sheep. If, during the grazing period, the areas previously used for conserved fodder preparation are successively included in grazing, the animals can always be offered protein-rich fodder with enough energy density and an adequate crude fibre content; or the fodder surpluses that cannot be managed through grazing can be skimmed off at the respective optimal time. This form of use offers high economic efficiency due to low labour requirements and the possibility to use large areas. Where possible, this requires rounded-up areas. The type of management also has a positive influence on individual animal performance and health. Continuous grazing at a stocking density < 2 LSU/ha and a grazing break in winter can develop a dense sward.

Meat quality

The best meat quality is achieved with young lambs under six months, with a weight at the end of fattening (ram at least 43 kg, female at least 38 kg) and a slaughter rate of about 48%. Other important quality characteristics are the distribution of fat and the texture of the meat.

What is the best way to market the produced sheep meat?

It is mainly done through direct marketing. Through direct customer contact, special quality characteristics of the meat as well as the husbandry conditions of the animals can be pointed out. The meat of some breeds is characterised by good, game-like flavour properties and low-fat content. There are also good marketing opportunities for lamb and mutton in special organic butchers and natural food stores.

Are there certification systems available and what advantages do they bring?

Organic labels or regional brands can have a positive effect on the local and regional marketing of the products. Examples are the EU organic logo or logos of farming associations such as Bioland, Naturland or Demeter.

What are the examples of the extensive sheep farming on fens?

In the Diepholzer Moorniederung (Germany), peatland management has a long tradition. Local landscape management association was founded in 2018 in order to support the shepherds economically and at the same time preserve the moor landscape. The main aim was to establish a regional slaughterhouse in order to be able to market the sheep meat with a guaranteed origin.

How does the process affect the greenhouse gas emissions?

Groundwater levels between 15-45 cm below ground level (soil moisture class 3+) ensure permanent aeration of the upper peat layer, promoting oxygen-dependent decomposition processes, peatland subsidence and shrinkage. Site emissions of about 16-19 t CO_2 equivalent $ha^{-1}\ yr^{-1}$ can be expected. In comparison, drained arable land on peat emits more than 30 t CO_2 equivalent $ha^{-1}\ yr^{-1}$ moist pastures with sheep are among the low peat-consuming practices. A reduction of greenhouse gas emissions and a prevention of progressive peatland degradation can only be achieved by raising the water level further. However, even among the robust sheep breeds, only a few (e.g. White Polled Heath) can cope with significantly higher water levels. Other livestock, such as water buffalo and red deer, are better adapted to water levels close to the soil surface, which are truly peat and climate-friendly. Therefore, from a climate protection point of view, sheep farming at water level 3+ only makes sense for areas where a water level at field level cannot be completely restored.

Effect on biodiversity

There are no detailed studies on the effects of sheep grazing on the biodiversity of the fens. However, it can be assumed that extensive sheep grazing changes the high-growing and species-poor vegetation stands and creates a species– and structure-rich vegetation mosaic. Respective food preferences of the different grazing animals play an important role. Sheep are considered to be selective grazers, but they also consume herbs and woody plants to a greater extent. Additional gaps for pioneer species can be created by stepping stones at frequently used passages. Seed dispersal through faeces and fur of grazing animals also takes place. The structure-rich vegetation mosaic creates a high habitat diversity for fauna. Spiders and insects benefit from the diverse structures. Areas kept free of vegetation by trampling provide important feeding and breeding habitat for several bird species. However, trampling by grazing animals can also harm fauna (especially meadow birds). In order to avoid trampling damage to existing nests or young birds, it is recommended to observe adapted periods of use. In the case of additional mowing, the use of biodiversity-friendly techniques (e.g. high cutting, oscillating instead of rotating mowers) and the establishment of one-year rotating fallows is recommended.

Costs and revenues

The costs and revenues (in € per ha per year) are taken from literature in Germany. It is assumed that 450 ewes are kept. The favourable scenario assumes 1.5 LSU ha^{-1}, the medium scenario – 1.15 LSU ha^{-1} and the unfavourable scenario – 0.8 LSU ha^{-1}. Different working time requirements were taken for the favourable, medium and unfavourable scenarios (9.6; 7.4 and 5.9 hours per ewe, respectively) and the prices (maximum, mean and minimum). Breed-specific differences in lambing yield and slaughter weight were taken into account for the yields. In the most favourable scenario (intensive breed) 1.4 lambs per ewe were assumed with a slaughter weight of 40 kg each. In the middle scenario, yields of semi-extensive breeds (per ewe: 1.3 lambs with a slaughter weight of 38 kg), and in the unfavourable scenario yields of extensive breeds (per ewe: 1.2 lambs with a slaughter weight of 30 kg) were assumed. Furthermore, revenues for old ewes (one fifth of the old ewes replaced per year), wool and solid dung are included in the benefits.

All examples in Table 13 show that sheep keeping under German conditions is only profitable if any subsidies are available. The incomes from meat and wool sales, even in the favourable scenario example, do not cover the costs at all.

Table 13.
Costs and revenues of sheep farming in Germany per hectare per year (Birr et al. 2021)

		Unfavourable scenario	Medium scenario	Favourable scenario
Costs incurred	Variable special costs/ material costs	-667 €	-958 €	-1.250 €
	Fixed special costs	-161 €	-232 €	-302 €
	Labour costs	-768 €	-851 €	-885 €
	Total	**-1.596 €**	**-2.041 €**	**-2.437 €**
Gross revenues	Yield	352 €	935 €	1.998 €
	Subsidy for grassland	100 €	256 €	680 €
	Subsidy for livestock	0 €	117 € (max 300 €)	None for intensive breed
Profit		-1.144 €	-733 €	241 €

Recommendations

Keeping any breed of sheep on rewetted peatlands is not recommended because maintaining the flock requires too low groundwater levels, at which the peat will continue to decompose and GHG emissions will continue. Only buffalos, ducks and geese are part of paludiculture and can tolerate the rewetted conditions. However, when it comes to rewetting of the large areas drained long time ago, we can expect that not the whole area can be flooded, due to unfavourable water conditions in the whole catchment area. So, modelling should be performed for each area for prediction of the expected groundwater level, and based on the prognosis and water level, the area should be divided into the plots by the types of the most economical promising options. Therefore, options other than buffalo, ducks, and geese should be considered in areas that cannot be rewetted due to their hydrological features.

5.8.4 Pasture with cattle
(modified from Birr et al. 2021)

Robust cattle breeds with low weight are suitable for the extensive management of moist lowland peatlands grassland with a lower carrying capacity than more heavily drained fresh grassland. Suckler cow husbandry[33] and the fattening of young female cattle play a central role in animal-friendly and at the same time lowland peatlands-compatible land management.

Which cattle breeds are suitable for extensive grazing on wet peatland sites?

The extensive robust breeds as well as some medium-intensive cattle breeds are suitable for extensive moist grassland use, i.e. at water levels of 15-45 cm below soil surface level. Due to their low weight, extensive or robust breeds cause less trampling damage than the medium-intensive breeds and the intensive breeds. In addition, they make lower demands on feed and husbandry and are also more suitable for year-round outdoor husbandry. Their robustness, relatively low weight and ability to move skilfully over difficult terrain distinguish them from the intensive breeds. Of the medium-intensity breeds, the smaller and lighter ones with good roughage conversion can be used. Typical peatland species such as reeds, cattails and reed canary grass are readily eaten by robust cattle. Shallow inundated areas up to 50 cm deep are also acceptable.

The table below gives an overview of cattle breeds that are suitable for production-oriented suckler cow husbandry as well as biotope maintenance on wetland sites.

Which extensive types of the production are suitable for grazing on wet peatland grassland?

In suckler herd husbandry as an extensive form of cattle husbandry, one marketable calf is raised per year and per suckler cow. The calves start eating grass within three months. If the suckler cows give enough milk, grass intake is still quite low at nine months. Besides suckler herd husbandry, fattening of young female cattle is suitable for extensive grassland use. In contrast to bull fattening, heifer fattening is also possible with basic forage growing on poorer sites.

We fully assume that there are local breeds of cows in Ukraine that are adapted to growing on wet soils, but were not taken into account in this study.

Pasture with cattle

Water level:	20 - 45 cm below ground in summer, 15 - 35 cm below ground in winter (soil moisture class 3+); also, temporarily or generally higher water levels (soil moisture class 4+) are possible.
Cultivation:	Wet pastures that have developed naturally after water levels have risen or deliberately through seeding.
Yield:	Growth 600-800 g per day (depending on breed)
Density:	0.8-1.5 LSU (Live Stock Unit) ha^{-1}
Utilisation:	Meat, possibly milk
Projected long-term site emissions:	~16–19 t CO_2-eq. ha^{-1} yr^{-1} (soil moisture class 3+) ~8–12 t CO_2-eq. ha^{-1} yr^{-1} (soil moisture class 4+) with the use of GEST approach

33 See the explanation on page 14

Photos 56, 57.
Left: Scottish Highland Cattle (Wichtmann 2009), Right: Relatively light and wetland-adapted Fjäll breed in the Rhinluch (Brandenburg, Germany). (Birr 2019).

What size of area extensive pasture use needs to be economically viable?

Profitability depends on many factors and is not primarily a function of the size of the area. In the case of extensive breeds, the sales opportunities must be studied, which are often limited to direct marketing or marketing of breeding animals.

Extensive grazing with herd of suckler cows of extensive and medium-intensive breeds without mineral nitrogen fertilisation is less labour– and cost-intensive compared to dairy cow husbandry and cattle fattening. Year-round outdoor rearing results in an effort and total cost saving of 25-30% compared to winter indoor rearing. Complex housing facilities and supplementary feeding with concentrated feed are not needed. In addition, due to their good adaptability to the climate, good robustness and light calving, veterinary and treatment costs are lower.

Table 14.
Selection of light cattle breeds suitable for suckler herd husbandry and their characteristics for extensive fenland management of wet sites.

Cattle breed	Weight*, Characteristics	Production line	Demands on climate and food	Does this breed exist in Ukraine
Aberdeen Angus[34]	450-550 kg, easy calving, nor aggressive, hornless	Meat	robust, adaptable, undemanding	yes
Dexter[35] cattle	300–350 kg, long-lived, small physique, but poorly calved	Meat, milk	Undemanding, good roughage utiliser, robust	yes
Fjäll	380–420 kg, fertile, long-lived, good-natured, hornless	Meat, milk	Adapted to harsh climate, frugal, wide hoof for wet areas	most likely no
Galloway[36]	400–500 kg, easy calving, wide hoof, hornless, peaceable	Meat	Robust, undemanding, wide hoof for wet areas	Robust, undemanding, wide hoof for wet areas
Heck cattle / Aurochs	550 kg, disease resistant, not aggressive, long horns	Meat	robust, frugal	no
Hinterwald	400–450 kg, light calved, long-lived	Milk, meat	robust, undemanding, low maintenance requirement	no
Murnau-Werdenfels Cattle	500–600 kg, long-lived, fertile, temperamental	Milk, meat	Adaptable to harsh climate, frugal	no
Highland [37]	400–580 kg, long-lived, not aggressive, long horns	Meat	Weather hardy, undemanding	Weather hardy, undemanding

** female cattle*

34 Breeding company Bondarivske LLC https://kurkul.com/kompanii/2362-tov-bondarivske (Zhytomyr), SHP Dnipro LLC: https://kurkul.com/kompanii/2361-tov-sgp-dnipro (Khmelnytskyi Oblast), Agro-Region Stud Farm LLC https://kurkul.com/kompanii/2360-tov-pleminniv-zavod-agro-reqion (Kyiv Oblast)

35 Breeding company https://kurkul.com/kompanii/2367-pap-aqroprodservis

36 Breeding company STOV Cherkasyplemservis (Cherkasy) https://kurkul.com/kompanii/2368-stov-cherkasiplemservis

37 Breeding company PAP Agroprodservis https://kurkul.com/kompanii/2367-pap-agroprodservis

The meat of robust and medium-intensity breeds is characterised by good taste properties and low-fat content, which can be considered an additional selling point. Nevertheless, the specific characteristics of each individual breed must be taken into account. Their suitability for extensive rearing on moist lowland grassland also depends on their weight and their breed-specific behavioural traits.

What you should consider when buying or from whom you should buy?

Once the decision for a breed has been made, it is recommended to contact a farm or pasture project that works with the same breed in order to establish contacts with the breeders. If there is no suitable pasture project, you may search contacts directly to a cattle breeding association. The purchase price is difficult to calculate, as the markets are very small and prices fluctuate greatly. If the price is very low in comparison to other offers, you should be careful. Sometimes these are animals that have been sorted out for breeding reasons or because of their behaviour.

What herd size is recommended?

The top priority when choosing the herd size is animal-friendly and fen-friendly husbandry. It depends on the following:

- site conditions (soil and vegetation conditions, structure and size of the area),
- assurance of the necessary animal control,
- technical possibilities of roughage feeding for the winter period (required feed quantities, storage, transport costs).

If the appropriate conditions are met, 20-30 animals, corresponding to a natural herd size of wild cattle, can also serve as a rule of thumb for domestic cattle breeds. Furthermore, with a herd size of about 30 cows and one to two bulls, a good mating performance of the bulls can be expected. A stocking rate of 0.8 to 1.5 LSU/ha can be considered as a guideline.

What should be considered when keeping animals outdoors all year round?

Year-round outdoor housing on (very) wet lowland peatlands is only recommended if the territory also has sandy or mineral soil areas where the animals can retreat when water levels are too high and at night. Furthermore, healthy and well-conditioned animals that have gradually become accustomed to outdoor housing and the falling temperatures are a prerequisite. Besides, attention should be paid to a balanced age structure of the herd with experienced animals. Even though some cattle breeds, such as Galloways and Highlands in particular, are considered robust, year-round outdoor husbandry always requires year-round weather protection from cold, wet, wind and heat. As protection against the cold, they should be provided with a pasture shelter on a dry site that offers a sufficiently large lying area for all animals. As a guideline, cattle weighing up to 500 kg should have a lying area of 4 m^2 (hornless) or 6 m^2 (horn-bearing), and cattle weighing over 700 kg should have a lying area of 6 m^2 (hornless) or 8 m^2 (horn-bearing). The lying areas should be regularly littered with dry material and should not be more than 100 m away from the feeding area. Furthermore, a frost-proof drinking water supply and supplementary feeding should be provided in winter. In free-range systems, cattle have a greater energy requirement than in stables. The additional energy requirement can be up to 10-20% of the maintenance. If the feed is not given daily, a covered and protected place for storing the fodder should be set up in the best possible way, e.g. covered hay stack (field barn) with movable feed fence, earth silo with movable feed fence, feed wagon with roof. Stocking density, feed supply and number of feeding places must also be coordinated in a 1:1 ratio. In addition, larger woods, bushes and groups of trees can provide shade in summer and wind protection.

What are the advantages of the partial grazing system?

The full grazing system, in which the grazing animals must feed on the growth of the wetland during the entire grazing period, is often not economical to operate. Therefore, good grazing management is crucial so that even wetter vegetation areas can be grazed by cattle. The prerequisite, however, is dryer mineral soils that are directly adjacent to the organic areas. If the area is used as standing pasture with free choice of forage, the wet areas will be only sporadically visited in spring, while at the same time there will be a high grazing pressure on the mineral sites. In spring, moist and wet areas also have forage growth of relatively good quality, which, however, decreases rapidly during the year, which is why the areas have to be grazed at the ideal time. Areas with better forage values on mineral sites can therefore be fenced out from June and mown as a hay reserve for the winter (about 40% of the mineral grassland). At the same time, grazing on the moist and wet areas with passable forage value will be enforced in June (partial grazing). Otherwise, these areas will not be visited until late summer and will no longer provide an adequate nutritional basis for the grazing animals. With far-sighted partial grazing management, liveweight gains of 800 g per animal per day are possible in the summer season at stocking rates below 1.5 animal unit/ha, even without supplementary feeding.

What should be considered in herd management?

If the herd is kept outdoors all year round, calving in the winter months should be avoided, as young calves have a much lower cold tolerance than adult cattle. If possible, the calving should be organized in such way, that it will take place from spring to summer months. To meet the optimal calving date in March/April, bulls should only be used for mating for six to eight weeks (June-August) and should run with the herd. If calving is expected in winter, stabling is necessary.

What are the relevant aspects of care and health care?

Competent care of the animals is a basic requirement. The herd should be visited daily and checked for signs of disease. If the animals are left on their own for a long time, diseases will be detected too late and any solution and veterinary care can become a problem. The mobility that Galloways and Highlanders are said to have can only be achieved with ongoing care.

Signs of unwellness are drooping ears that often appear in combination with apathetic behaviour towards the environment. Further indications could be: seclusion from the herd, conspicuously long periods of lying down, hunched up standing, no ruminating activity as well as an empty rumen (so-called hunger pit on the left side). Respiratory diseases can be recognised by clearly strained breathing, in severe cases by whistling or rattling noises and coughing as well as nasal discharge. In this case, pneumonia or lungworm infestation should also be suspected. In case of any of these signs, urgent action is required.

The necessary parasitological care of the animals depends on the herd and location. Vaccination of the female cows minimizes calf rearing diseases (coli septicaemia, coli enterotoxaemia, infectious respiratory diseases). In addition, regular blood tests are mandatory for cattle, annual examinations for bovine herpes (BHV-1 virus) and testing for brucellosis and leucosis every three years. A veterinarian should always be consulted in case of changes in the flare mouth that are not due to sun exposure. A number of notifiable animal diseases are manifested by changes in the mucous membrane of the muzzle (e.g. BHV-1, BVD/MD, BKF and foot-and-mouth disease).

How should endoparasites be treated?

Liver flukes, which infest cattle as the final host and which, in the case of severe infestation, are treated several times with the anthelmintic medicine in high doses, are regarded as a major animal health problem on humid sites. To prevent resistance, the treatment should be selective and not applied to the entire livestock.

In general, there are ways to control liver fluke infestation in pasture management: free access to water accumulations where the dwarf mud snail lives can be restricted. Wet meadow hay that is turned in early summer and, if necessary, fed in winter should be stored for six months or ensiled for 30 days to ensure that all infective stages of liver fluke are killed. Worm burden is reduced by early summer mowing, as overwintering larvae are removed from the area. Furthermore, the recommended extensive stocking density reduces the likelihood of the animals becoming infected. Labour-intensive portion grazing with short residence times of the animals and long rest periods also minimises contact between infectious parasite stages and their hosts.

While using medication to treat parasitic worms, it should be noted that conventional drugs such as avermectins and their degradation products are toxic and are largely excreted in the faeces. Particularly harmful are boli and long-acting medicines – which constantly release active substance over a long period of time and could thus impair the development and reproduction of coprophagous insects over the entire grazing season.

If treatment of livestock because of the worms becomes necessary despite all preventive measures, the risk of damage to coprophagous insects can be reduced as the following:

- avoid unnecessary (e.g. prophylactic) treatments,
- do not treat all animals on one area at the same time,
- place treated animals (young cattle) next to untreated animals (cows) on the grazing area,
- temporary stabling of avermectin-treated animals (approximately for 2 weeks),
- use ecologically safe active substances (benzimidazoles, levamizole) in early summer and summer during the main insect reproduction period.

If the animals graze on soft and moist soils, regular hoof monitoring and care is necessary. Moist sites can be the source of hoof diseases. Suitable trapping equipment should generally be available for veterinary treatment in the event of disease or epidemic (even on small farms). Most complications occur in suckler cows around birth. Calves are susceptible to disease, especially in the first weeks of life, and as young animals they are much more sensitive than adult animals.

What must be considered in the management of the grazing area?

To prevent the spread of undesirable species, such as tufted hairgrass (Deschampsia cespitosa), rushes (Juncus spp.), thistle (Cirsium spp.) or dock species (Rumex spp.), which are promoted by selective grazing, as well as to remove overstaying fodder and ridge areas, a post-mowing (flailing, mulching) should be carried out. This simultaneously suppresses the emergence of woody plants such as willows and alders as well as the seeding of the undesirable species. Alternatively, to control the above-mentioned species, which can be an indication of undergrazing, the stocking density can be increased or the animals can be allowed longer feeding times in the paddock. Overgrazing, on the other hand, is manifested by an increase in tread-resistant species such as creeping bentgrass, broadleaf plantain or silverweed, which should be responded to with lower stocking rates or longer rest periods.

What should be avoided?

Activities which are recommended for grasslands on mineral soils and for drained peatlands like pressing soil layers after winter by turf rolling, raking, re-sowing, manuring grasslands with organic fertilizers etc. can be done only if the water table in spring is deep enough that the trafficability of the soil is good for heavy machinery – this means about -40 up to -60 cm in April. If such water tables are installed early in the year this means that waters from winter rains are drained out of the area which will end up at deep water tables of about -100 cm and deeper, if no additional waters can be used for irrigation in summer. This means that such kind of management is extremely peatland degrading. This cannot be reasonable and contradicts all efforts to mitigate climate change. As well, manuring rewetted peatlands is not allowed! The negative consequence of this is that in rewetted areas, higher quality requirements for fodder must be dispensed with.

In addition to the above-mentioned species with inferior feed value, it is important to watch out for the spread of poisonous plants such as marsh horsetail (Equisetum palustre), autumn crocus (Colchicum autumnale), celery-leaved buttercup (Ranunculus sceleratus), ragwort (Jacobaea vulgaris), water ragwort (Jacobaea aquatica), bittersweet nightshade (Solanum dulcamare) and water hemlock (Cicuta virosa).

What are the advantages of the mown pasture system?

With mowed pasture, the area is occasionally mown in addition to the use as a pasture. The stand resembles a pasture; there are clear differences to meadows. The higher frequency of use leads to a greater proportion of undergrass and an increased occurrence of tread-tolerant rosette plants. The sequence of cutting and grazing depends on the forage growth. Mowing takes place once or twice during the vegetation period, with the focus on pasture use. We recommend only extensive mowing pasture practices.

In contrast to extensive meadow use, mown pastures offer the possibility of continuously providing improved quality fodder for the cattle. If, in the course of the grazing period, the areas previously used for the preparation of preserved fodder are successively included in the grazing, the animals can always be offered fodder with higher energy density and an adequate crude fibre content, or the fodder surpluses that cannot be managed through grazing can be skimmed off at the respective optimal time of use. This form of utilisation offers high economic efficiency due to low labour requirements and the possibility of utilising large areas. The management system also has a positive influence on individual animal performance and health. Continuous grazing at a stocking density < 1.5 animal unit/ha and a grazing break in winter can develop a dense sward.

The gain in live mass

The gain in live mass of robust breeds such as Galloways and Highlands is comparatively low. An annual average daily gain of 600 g can be assumed for male Highland cattle. Growth rates of about 800 g per day can be expected for medium-intensity breeds in the partial grazing system. Growth rates for females are 5-15% lower than for young males.

What influence have a slaughter date, cold storage and maturation on the meat quality?

In a case of year-round grazing with little or no supplementary feeding in winter, animals should not be slaughtered from February to June. During this period, the animals have largely used up their fat reserves or have not yet sufficiently built them up again. The meat of these animals is tough even if processed in optimal way. Stress and strain caused by separation, capture, sometimes long transport routes and restraint immediately before slaughter not only impair animal welfare, but also lead to a limited maturing process of the meat, which has a negative impact on its quality.

In contrast, the so-called pasture shot can represent a consistent conclusion to species-appropriate animal husbandry. In this case, the animals are stunned by a shot to the head in the pasture in familiar surroundings and then killed by bleeding. The grazing shot requires good planning: in Germany, competent authority must be notified 24 hours in advance, a bullet trap and a good, experienced shooter are also necessary. Within 60 minutes, the animal must be transported to a certified slaughterhouse. The absence of stress is reflected in better values of various parameters (tenderness, meat colour, water retention capacity) regarding meat quality. Pre-mortem stress reactions are significantly lower with pasture shooting than with conventional slaughter. Ultimately, pasture shooting also serves as another positive selling point for meat from extensive free-range farming.

Before leaving the slaughterhouse, the meat must have a core temperature of 7°C. It must be considered that the production of high-quality meat also depends on the cooling rate of the carcass. If the meat is cooled too quickly immediately after slaughter, it may become hard due to the cold. This can be countered by gradual cooling to 14-19°C initially, followed by intensive cooling to 7°C. During the first week of maturing, the development of the aroma and tenderness of the beef is at its highest, which is why a two-week maturing period is considered optimal. A longer maturation period requires particularly high hygienic standards and special packaging technologies.

What is the best way to market the produced beef?

The marketing is mainly done through direct marketing, which is particularly important for the marketing of beef from extensive breeds. Through direct customer contact, special quality features of the meat and the conditions under which the animals are kept can be pointed out. There are also good marketing opportunities for organically produced beef in special organic butchers' shops and in the health food trade.

Are there certificates and what are their advantages?

Regional and organic labels can have a positive effect on the local and regional marketing of products. The associations of the robust cattle breeds also usually have their own quality labels. When switching to an organic farm, it should be noted that animals may only be purchased from herds with an organic certificate.

What is the effect of the process on the greenhouse gas emissions?

When cattle are kept at the fields with groundwater levels between 45 and 15 cm below ground level (water level class 3+), the upper peat body is permanently aerated. This promotes oxygen-dependent decomposition processes, peatland subsidence and shrinkage, and causes site emissions of ~16-19 t CO_2 equivalent ha^{-1} yr^{-1}. If cattle are kept at the fields with the higher water levels between 20 and 5 cm below ground level (water level class 4+), site emissions are expected to be ~8-12 t CO_2 equivalent ha^{-1} yr^{-1}. In comparison, drained farmland on peatland emits more than 30 t CO_2 equivalent ha^{-1} yr^{-1}. Cattle grazing is one of the low peat-consuming practices, so from a climate change perspective, cattle grazing only makes sense for (partial) areas where water levels cannot be fully restored to floodplain level.

How does management influence biodiversity?

Extensive grazing opens up high-growing and species-poor vegetation stands and creates a species– and structure-rich vegetation mosaic. The respective selective feeding preferences of the different robust breeds play an important role in this process. Additional gaps for pioneer species are created by stepping stones at frequently used crossing points. Seed dispersal through the faeces and fur of grazing animals also takes place. The structurally rich vegetation mosaic creates a high diversity of habitats for fauna, which is especially important for spiders and insects. Areas kept free of vegetation by trampling provide important feeding and breeding habitat for several bird species. However, trampling by grazing animals can also affect fauna (especially meadow birds). In order to avoid trampling damage to existing nests or young birds, it is recommended to observe adapted periods of use of the sites. In the case of additional mowing, the use of biodiversity-friendly techniques (e.g. high cutting, oscillating instead of rotating mowers) is recommended.

Costs and revenues

The costs were obtained from Kaphengst et al. (2005) for the cost items in which the stocking density plays a role (fodder, litter, etc.); the values were derived for a stocking density of 0.8 and 1 and 1.2 animal unit/ha respectively. The hourly wage for labour costs was increased from 12 €/h to 15 €/h. The values provided by Kaphengst et al. (2005) in combination with the given stocking density result in between 14 and 26 labour hours per animal unit. The calculation was based on 25 labour hours per animal unit, resulting in different costs for the three different stocking densities. In addition, the drinking water requirement was added to the variable costs. Based on the KTBL data (Das Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. – The Board of Trustees for Technology and Construction in Agriculture) for lactating and dry mother cows, rearing calves and young cattle with medium drinking water requirements, the assumed group composition results in a requirement of approximately 425 m3 per year. Depending on the herd density, different costs per ha result. For the fixed costs, the maximum costs were chosen from Kaphengst et al. (2005) for the unfavourable scenario, the medium costs for the medium scenario and the lowest costs for the favourable scenario.

It is assumed that 20 suckler cows are kept with 2 calves per 3 cows per year. The male calves are slaughtered at the age of 8 months weighing 250 kg as dairy beef cattle. The young female cattle are further fattened (separated after 6 months) and slaughtered at the age of 18 months with a weight of 450 kg. The proportions of marketable beef cuts (e.g. rump steak, goulash meat, minced meat) in the total weight were taken from the data for water buffalo and converted to the two slaughter weights (calf 250 kg, heifer 450 kg). The prices for the respective beef cuts were taken from Scholz (2019); these are lower than the prices for buffalo cuts from Sweers et al. (2014), resulting

Table 15.
Costs and revenues of cattle farming in northern Germany per hectare per year

		Unfavourable scenario	Medium scenario	Favourable scenario
Costs	Variable costs	-145 €	-175 €	-202 €
	Labour costs	-300 €	-374 €	-450 €
	Fixed costs	-57 €	-47 €	-40 €
	Total	**-502 €**	**-596 €**	**-692 €**
Income	Yield	1.079 €	1.012 €	1.214 €
	Subsidies for grassland	100 €	235 €	680 €
	Subsidies for livestock	0 €	45 €	181 €
Profit		**677 €**	**696 €**	**1.383 €**

in a revenue of about €1,632 per male calf and €2,938 per young female.

In the unfavourable scenario, 0.8 animal unit ha^{-1} are kept, in the medium scenario 1 animal unit ha^{-1} and in the favourable scenario 1.2 animal unit ha^{-1}. Depending on this, different numbers of dairy beef cattle and young female cattle are slaughtered per ha and year.

Cow breeds in Ukraine from the Polissia region

In the 19th – at the beginning of the 20th century, there was a Poliska breed of cattle in Polissia, which was adapted to the peculiarities of keeping in this territory: mostly swampy terrain, vegetation poor in nutrients: sour grasses, sedges, rushes. The waterlogging of the meadows was sometimes so significant that in rainy summers it was not possible to remove the hay and the animals "grazed", sometimes getting stuck up to their bellies.

It was mentioned that the cows of the Poliska breed did not eat a poisonous yellow rhododendron (Azalea pontica), from which livestock unfamiliar to Polissia vegetation got sick and died. Unfortunately, the corresponding Poliska breed disappeared in the 20th century (Rieznikova, 2022).

Red Polish is the oldest breed of cattle in Poland, which has the following advantages: good adaptability, resistance to diseases, including hoof diseases, adaptation to nutrient-poor vegetation. Before World War II, this breed was popular throughout Poland (including the territory of the current Ukraine). Now Red Polish accounts for approximately 1% of the total number of cows in Poland[38].

There are two breeds of cattle that were bred at the end of the 20th century in Ukrainian Polissia: the Volynska Beef breed and the Poliska Beef breed. Both breeds feel good on pastures.

Volynska Beef was bred specifically for Polissia and Prykarpattia of Ukraine, where meat breeds of cattle do not acclimatize well. Red Polish, an old breed of cattle, was used to create Volynska Beef breed.

Poliska Beef breed was created on the basis of the old Ukrainian Grey cattle[39]. The new breed was aimed to achieve the genetic improvement of the Polissia zonal type of animals.[40] .

Using a herd of Ukrainian Grey cattle in a project for the environmental restoration of the island of Malyi Tataru in the Danube Delta (based on materials prepared by N.M. Fursa) (WWF Ukraine 2019)

The Ukrainian Grey breed is the only indigenous breed in Ukraine that has not been crossed with foreign genotypes. At the beginning of the 20th century, it was a universal breed in Ukraine – the main source of milk, beef, and draft power. At that time, there were up to 5 million heads of cattle.

Despite the antiquity of the gene pool, the Ukrainian Grey breed adapts perfectly to modern conditions and shows high productive and reproductive potential at the level of the best world meat breeds. Animals of this breed are distinguished by high live weight, young animals have significant growth energy (900-1100 g per day). Cows are very prolific: each cow gives birth to a calf once a year; up to 10% of cows can calve twice a year; a fairly high percentage (up to 6%) of twins.

Malyi Tataru Island is located in the Danube Delta. During Soviet times, its perimeter was separated from the Danube by a dam for agricultural use. In 2003-2004, the dam was dismantled, and in 2005, 10 heads of the Ukrainian Grey steppe breed of cows were brought there. It was assumed that cattle would become the main tool for managing the reed thickets on the island after the natural hydrological regime was restored. Since 2005, the herd has been grazing freely, and in June 2018, 35 heads were recorded on the island.

38 http://www.pfhb.home.pl/www/english/index.php?strona=breeds.htm

39 https://agrostorv.com/info-centre/zivotnovodstvo/sovremennye-ukrainskie-porodv-krs/

40 https://kurkul.com/porody/69-poliska-myasna

In extreme, completely new environmental conditions for the Ukrainian Grey breed, a population of highly adapted animals has formed in sufficient numbers, which is steadily reproducing. After all, the herd, having been in the wild for a whole year, without any help from humans, managed to survive, successfully reproduce and continue to develop.

Advantages of the Ukrainian Grey cattle breed in environmental restoration projects:

- Strong constitution, high adaptability, resistance to diseases
- Strong hoof horn, absence of hoof diseases in a humid environment
- Thick elastic skin – reliable protection against insects
- High fertility and high viability of young stock
- Excellent development of the gastrointestinal tract, capable of digesting coarse plant and branch food
- Developed herd instinct – the basis of protecting the young and the viability of the herd
- Strong maternal instinct
- Smartness, good ability to navigate in the environment

5.8.5 Conclusions for livestock farming on wet peatlands

As an exemption, grazing with water buffaloes (Bubalus bubalis) for meat production and the fattening of geese seem to be particularly suitable part time flooded peatlands, when water levels are corresponding to soil moisture class 4+/5+, because there the soil moisture class 4+ already seems to be peatland-preserving. Since trampling compacts soil, the decomposition is reduced to a minimum. Buffaloes accept water levels near surface and forage biomass with low energy contents. Keeping geese is not a problem even at higher water levels anyway. Wet grassland management with buffaloes is an upcoming approach performed in several nature conservation projects, at least in Germany (Wiegleb and Krawczynski 2010). From the economic perspective, keeping water buffaloes only appears to be "economically viable", provided the meat is marketed directly. From what we have observed so far in the Northern Germany, milk production with buffaloes (and with dairy breeds anyway) fails on unfertilised wet grassland due to insufficient forage quality as the potential milk yields are rather low. However, under different economic condition of other countries, it could be different.

Ecosystem services of livestock (especially water buffaloes and geese) based management on wet peatlands are the following:

- Meat, other products
- Maintenance and landcare, keeping landscapes open,
- Biodiversity (vegetation, beetles, birds, etc.),
- Mitigating the effects of climate change, improving water quality.

Besides water buffaloes and geese keeping, all other animal-based concepts for the management of rewetted peatlands must be viewed with caution, as they disregard the climate function of the peatlands due to the lower water levels and do not deliver the ecosystem services mentioned above.

5.9 Other uses of peatlands

Besides a number of possibilities (some are described below) rewetted peatlands can give space to eco-tourism especially if a corresponding infrastructure is offered like observation towers, ecologic trails and marked trails, as well as opportunities for bird watching or hunting (Tanneberger and Wichtmann 2011). For more information please see (Tanneberger and Wichtmann 2011), page 108.

5.9.1 Medicinal plants and medicines

The production of sundew (Drosera rotundifolia) is an option to be cultivated in raised bog peatlands together with peat mosses (Sphagnum spec). Exhausted peat deposits show potential for the cultivation of medicinal and melliferous herbs native to peatlands. In Belarus more than 50 species of peatland plants are used as raw materials for the pharmaceutical industry or are good melliferous herbs. These officinal plants are either gathered from natural stands or can be cultivated in re-wetted peatlands. Some understanding of officinal plants has been gained with experiments on bogbean Menyanthes trifoliata, hemp agrimony Eupatorium cannabinum, meadowsweet Filipendula ulmaria, sweet calamus Acorus calamus, and European bugleweed Lycopus europaeus in Northeastern Germany. They can be successfully cultivated on land with a high water table (Tanneberger and Wichtmann 2011).

Cultivation of herbs

Cultivation of medicinal plants is considered one of the most promising niches in agribusiness for Ukraine[41]. In 2017, Ukraine exported medicinal plants worth 7.5 million dollars, in 2022 – for 12.5 million dollars. Experts estimate the profitability of production at 46% in the first 4 years. In the following years, profitability will be even higher. The list of paludiculture medicinal plants is given in Table 2.

According to the State Statistics Service of Ukraine, the cultivated area of medicinal plants is 3.8 thousand hectares, and the total volume of production is 27 thousand centners[42].

The advantage is that the companies engaged in the processing of medicinal plants actively offer cooperation to the farmers and undertake the processing of raw materials, transportation, marketing, and sales.

Among the plants considered paludiculture, a large number of medicinal plants grow in wild. Probably, their collection and cultivation can be combined with beekeeping.

Below are three companies that can become partners.

Herbs Zaporoje TM *https://travizaporoja.com.ua/*

Cultivation and harvesting of medicinal plants, production of phytoproducts, development and production of equipment for working with medicinal plants.

The assortment includes about 200 plants.

Growness Group *https://growness-group.com/*

The largest exporter of medicinal raw materials in Ukraine. They harvest, process and sell more than 1.5 thousand tons of dried products per year. Storage and processing is carried out in warehouses near Ivano-Frankivsk. The area of warehouse and production premises reaches 7,000 m^2.

They cooperate with more than 100 farmers and collectors from most regions of Ukraine. They have an organic label.

Shlosem Ukraine LLC *https://shlosem.com/about/* is an agro-pharmaceutical company engaged in cultivation, procurement of medicinal and aromatic plants, production of extracts and essential oils and functional (prophylactic and health) products from them.

Cultivation and manufacture of products will be carried out both at our own production areas and at the partners' facilities located in Cherkasy, Zhytomyr and Volyn Oblasts.

Honey production

Ukraine is one of the world's top three honey importers. Honey is a niche product recommended for production by experts[43].

Therefore, the number of farmers engaged in beekeeping in Ukraine is increasing and, accordingly, it is necessary to increase the area where bees can collect honey.

41 https://kurkul.com/spetsproekty/332-top-5-nayperspektivnishih-likarskih-roslin-dlya-fermeriv

42 Growing medicinal plants as a business – AgroApp: Fast lending for agribusiness

43 Cherevko H., Cheverko I. (2020). Efficiency of Niche Agriculture in Ukraine. Problems of World Agriculture, 20(4), 18-28; DOI: 10.22630/PRS.2020.20.4.19.

The idea of using soils unsuitable for agriculture as an area for cultivation of honey-bearing plants is proposed by the farmers themselves .

Honey-bearing plants that are growing on wet soils have several advantages and can be used for industrial honey collection. The peculiarity of swamps is the presence of constant honey-bearing plants even in hot weather, since plants have enough moisture and nectar are released constantly (Bodnarchuk et al. 1993), which is an advantage in view of a changing climate.

Mire vegetation is important for the development of beekeeping in Polissia. Mire vegetation is a good option for bees in the spring, when the intensive development of bee colonies takes place. It is especially valuable that melliferous plants start blooming from early spring before the flowering of white acacia. Swamp heather, which grows in mires, is one of the 10 best honey bearing plants of Ukraine[44].

A list of natural Polissia melliferous plants with an indication of the amount of honey per 1 hectare is given below.

Ledum palustre (marsh Labrador tea) – 60-70 kg per 1 ha, Salix cineria – 60-70 kg per 1 ha, S. pentandra, S.myrtilloides L., S. lapponum – willows, Lysimachia vulgaris (yellow loosestrife) – 20-25 kg per ha, Alnus glutinosa (alder), Comarum palustre (marsh cinquefoil)– 25-30 kg per ha, Polygonum bistorta (bistort) – 40 kg per ha, Geum rivale (water avens) – 100– 150 kg per ha, Archangelica officinalis (angelica), Epilobium hirsutum (great hairy willowherb), Caltha palustris (marsh marigold), Lychnis flos-cuculi (ragged-robin) – 65 kg per ha, Petasites hydridus (the butterbur), Frangula alnus (buckthorn), Mentha aquatic, Iris pseudacorus (the yellow flag), Butomus umbellatus (flowering rush), Populous nigra (black poplar), Stachys palustris (marsh woundwort), 100-120 kg per ha.

Beekeeping can be combined with the cultivation of medicinal herbs in paludiculture fields.

The National Scientific Centre "P.I. Prokopovych Institute of Beekeeping" (http://prokopovich.com.ua/) includes a Sector of Economy, Production Organization and Development of the Forage Base of Beekeeping.[45]

5.9.2 Willow (Salix spec.)

(modified from Birr et al. 2020)

Willows can be used for rather different purposes: short coppice plantations can be used for bioenergy, one-year old shoots of willows (Salix spec.; see Photo 58) are traditionally used for arts and crafts, e.g. for wicker baskets or furniture like chairs and other useful things.

Shallow, degraded, moist agricultural land on fen – especially marginal areas of rewetted land – is in principle suitable for short rotation coppice (SRC). Pastures are suitable for short rotation of up to four years. SRC that are to be replanted after 20 years can only be recommended for rewetted, organic arable sites for climate protection reasons and according to the current conditions of fenland soil protection. At present, such plantations can only be recommended within the framework of pilot projects for research purposes. Here, monitoring should be integrated, which prominently considers aspects of biodiversity and climate impact.

Willow (Salix spec.) SRC cultivation

Water level:	20-45 cm below ground level in summer, 15-35 cm below ground level in winter (soil moisture class 3+)
Cultivation:	Plantation
Yield:	Growth depends on the variety, yields 3–6.3 t ha^{-1} yr^{-1} and intended use, several shoots are possible
Utilisation:	Energy wood, wicker work, baskets
Standard emissions:	Further research is needed

44 https://www.honeyprice.ua/blog/medoproduktivnost-rastenij/#10.-veresk

45 https://www.honeyprice.ua/blog/zhara-spasaem-pchyol-dumaem-na-perspektivu-o-metodah-selektsii/

What sites are suitable for willow plantation?

Willows can be cultivated in the form of short-rotation plantations on moist to semi-humid sites without permanent waterlogging (groundwater interval 15-45 cm below ground level). As they also tolerate temporarily wet soil conditions and even waterlogging, willows are a suitable management option for transitional areas between agricultural land with annual crops or grassland and wetter areas, where waterlogging can also occur temporarily. Willows can achieve good growth rates on shallow, degraded fen soils.

Which factors should be considered during cultivation?

If it is an arable land with directly preceding use, cultivating or ploughing in autumn is sufficient. Shortly before planting, the seeding ground should be prepared by shallow cultivation. If it is an arable fallow land or grassland, where ploughing or use of herbicides should be avoided, then either mulching or mowing must be carried out in preparation for planting. If the mown material is not used for other purposes, it should be left on the area to inhibit the regrowth of the accompanying vegetation, at least initially. In addition, the area can be prepared with a strip tiller, which significantly reduces the competition of the accompanying vegetation in the first weeks. The use of compostable film proved to be even more effective, whereby it is necessary to mill between the planting rows in order to be able to weigh down the film with soil on both sides. The disadvantage here, however, is the high labour input and thus increased costs.

What planting material can be used?

There are varieties of willow that are especially suitable for SRC. For example, Swedish varieties such as Tordis [(Salix viminalis x S. schwerinii) x S. viminalis], Tora (S. viminalis x S. schwerinii), Inger (S. triandra x S. viminalis) and Sven [S. viminalis x (S. viminalis x S. schwerinii)] are suitable. If it is possible to grow several willow varieties with similar growth performance, planting can be established in a stripwise mixture. However, it is possible that the individual varieties will show differences in growth performance on the given site.

The number of plants per area depends primarily on the production objective and the corresponding target rotation period. For target rotation periods from two to four years, planting between 8,000-15,000 plants/ha are recommended. When calculating the number of plants, it is also important to consider the optimal row spacing for cultivation, both for the maintenance technique and the harvesting concept. The planting distance within the row should not be less than 30 cm.

Photo 58.
Willow plantation at the edge of a wetland used for cutting brushwood for basket weaving, arts and crafts and other handicrafts, Dniester lowlands (Wichtmann 2017)

What planting method is optimal?

Basically, regardless the planting method, it is important to ensure that the plants are firmly seated in the soil and that there are no cavities. The choice of planting method depends on the planting material, the available technology and the moisture level of the area.

If the area can be driven over with heavy machinery and soil cultivation is possible without restrictions, mechanical planting is recommended. This is the most cost-effective option. In this case, 20 cm long cuttings that are continuously loaded manually into the special machines are firmly planted in the soil.

If conservation considerations are more important that the economic ones, i.e. ploughing up and/or the use of heavy machinery should be avoided, rod planting is chosen. If the area is not ploughed up, it must be ensured that the cuttings reach the capillary fringe of the groundwater and that the competing vegetation is kept short in order to reduce above-ground light competition. Planting can be done with machines, but also manually with planting drills. A hole of the desired depth is drilled with a planting drill of the smallest possible diameter. The cuttings are then inserted into the holes by hand and the surrounding soil is trampled down so that the planting material sits firmly in the ground. The mechanical establishment for a willow SRC costs around 1750 €/ha, with the planting material (incl. transport to the site) and planting (incl. personnel and travel) taking up the largest items at 1,000€ and 500€ respectively.

What is the best time for planting?

Planting should take place in spring (March-May) in calm, dry, overcast weather, as soon as the area is passable and the soil is frost-free, so that growth and sprouting is ensured before a possible spring drought. In addition, seedlings obtained in winter lose vitality if they are stored for too long. If there is no risk of desiccation, planting can take place a little later than usual until early summer, under condition that the planting material is continuously cooled at -2 °C.

Is regular care of the crop necessary?

Particularly in the year of the establishment and depending on growth possibly also at the beginning of the second year, regulation of the accompanying vegetation is necessary to minimise the competitive pressure for water and light of the plants. If the soil is passable and the appropriate row spacing for heavier machines is given, superficial machines such as cultivator or disc harrows can be used for maintenance. If you want to maintain the sward and preserve the carbon stocks in the soil, soil-penetrating machines are not recommended; instead, mowing or mulching should be carried out every 3-4 weeks. If there has been no area-wide tillage before planting, monthly mowing may be necessary in the first year. If the soil is too soft or the use of large machines is not desired, high grass mowers, other small mowing machines (with or without mulching attachment) or brush cutters can be used. The correspondingly more time and financial expenditure must be considered.

Is regular fertilisation necessary?

In contrast to the cultivation of annual crops, no additional fertiliser is required for SRC. By harvesting in winter after the leaves have fallen, some of the nutrients are returned to the soil. Drained fens also continuously replenish through the mineralisation processes of organic matter and the base richness of the groundwater.

What preventive pest control measures are recommended?

The greatest damage to young plants is caused by cloven-hoofed game animals (roe deer, fallow deer, and red deer). Browsing occurs mainly on young shoots of the willow. Sweeping damage also affects willow at a young age. Peeling damage only becomes relevant in older plants with developed stems. In general, it is advisable to plant large-scale SRC in areas with higher wild game populations, so that the game animal pressure is distributed. Appropriate hunting is the best solution to avoid major damage.

Near water bodies, beavers can cause damage to trees (observed started from 3 cm diameter). In this case, fences can prove to be an effective measure to protect the plantation. Especially on former fallow land with very deep drainage, an infestation of mice (water voles, Arvicola amphibius) can occur, but this only leads to relevant damage in exceptional cases. The insect pests blue willow beetle (Phratora vulgatissima), wireworms (larvae of click beetles, family

Elateridae) and sawfly (Nematus caeruleocarpos) can occur and sometimes cause severe economic damage. Beneficial insects such as Chalcid wasps (Chalcidoidea), robber– and hover fly species are important counterparts and can reduce or even completely prevent the spread of pests on SRC.

What is the best time for harvesting and why?

As a rule, harvesting only takes place during the period of dormancy from November to March to avoid damage and thus loss of plants' vitality. For mechanical harvesting, long periods of frost, during which the soil is deeply frozen, are essential to guarantee that the soil can be driven over. In a cultivation trial with the Tordis willow variety on rewetted fen grassland, yields between 3.0 and 6.3 t of absolutely dry matter ha^{-1} yr^{-1} (1st rotation, 4 vegetation years) could be calculated. In the Netherlands (Zegveld), good growth performance of a silver willow (Salix alba) stand established by cuttings (3 plants/m^2) was found on about 400 m^2 at medium water levels in corridor, with topsoil pushed off in advance. In contrast, at constant high water levels of 10-30 cm above ground or at low water levels of about 50 cm below ground, growth performance was moderate to poor.

What harvesting methods are recommended?

Short rotation plantations with the harvesting intervals from two to four years can be harvested in chop lines or in rod lines. In chop lines, a chipper and a tractor with trailer travel side by side in parallel. The trees are felled and chipped by the chipper in one operation and then filled into the trailer as wood chips. This method currently results in the lowest harvesting costs. The harvesting capacity of the chipper is about 40 t ha^{-1} (20 t of absolutely dry matter ha^{-1}), which corresponds to an area output of 1 ha/h for a two-year-old stand. Harvesting costs are around 27€/t of absolutely dry matter with a variation of 18-42€/t of absolutely dry matter.

In the case of rod lines, the trees are cut with suitable technology, e.g. from a stemster, and temporarily stored at the field edge. Transport to the field edge can be done by the stemster itself for rods up to approximately 200 m, for longer rows transport by a return vehicle is necessary, which causes additional costs. At the edge of the field, the rods usually remain for several months to dry and are only then chopped into wood chips. Drying of canes results in significantly lower dry matter losses than storing wood chips over the same period of time. The harvesting capacity here is somewhat lower than with the wood chip line, at about 26 t of absolutely dry matter /ha. The harvesting costs are around 25-45€/t of absolutely dry matter.

What harvesting technology is needed?

For the chop lines, forage harvesters or mounted choppers designed for front or rear attachment to tractors can be used. The harvesters can be adapted to the soil conditions with different undercarriages such as double or twin tyres or wide tyres with pneumatic control. Mounted choppers are less expensive than forage harvesters. They can be used for single-row and, in some cases, double-row cultivation of woody plants up to a cutting diameter of approximately 15 cm. The chopped material can then be fed directly into a hanger attached to the harvester. On the one hand, the rather coarse wood chips produced with cultivation chippers are very well suited for long-term storage, but on the other hand they can cause problems in small and medium-sized combustion plants.

Depending on the length of the harvesting intervals and thus the cutting diameter of the woody plants, different technology is used for the rod lines. For cutting diameters of the woody plants of less than 8 cm, harvesting can be carried out with mower collectors or mower bundlers, which can be followed by the processes of the chipping lines.

What special features need to be considered when storing the woodchips?

During storage, it is important to minimise microbial activity, which can lead to considerable losses of dry matter, and the spread of health-endangering moulds in the wood chips. The decisive factor is the size of the wood chips.

Due to the larger gaps and consequently better ventilation during storage, the coarse wood chips with a size of more than 80 mm dry down to approx. 20% moisture within one year in comparison to smaller wood chips. Both microbial activity and the proliferation of moulds can be reduced as a result. Furthermore, drying increases the calorific value and thus the technically usable energy.

Small quantities of small and medium woodchips can be stored in covered and well-ventilated halls. It is advisable to store large harvest quantities in conical or elongated, pointed stockpiles and on firm ground in the open air. The rainwater input can be reduced by covering with a compost fleece. Installation of aeration channels or technical drying, for example by using waste heat from biogas facilities, helps to improve quality.

What energy and products utilisation options are available?

The energetic utilisation of wood can take place in the form of wood briquettes, wood pellets, but usually as wood chips. In the production of pellets, the raw material is pressed through a die by means of rollers (rollers) and the pellet strands are cut to the desired length with a shearing knife. Due to their uniform quality, pellets are particularly suitable for power plants with automatic feeding. Wood chips can be marketed sorted by size and water content in bulk cubic metres. The capacity of wood chip plants ranges from 15 kW to several MW.

What are the quality requirements?

The marketing success of woodchips depends on the homogeneity of the material, the water content, the lumpiness, the ash content and the proportion of leaf residues. Average data for willow from SRC is presented in the following table.

Other utilisation options

Willow has regained importance as a pharmaceutical raw material plant in recent years. Many willow species contain salicylates, which are effective against pain and rheumatic complaints. Depending on the willow species, the bark contains 1.5 to over 11% salicylates with varying compositions. To obtain the extract, the twigs of one to three-year-old willows are first chopped and then the substance is extracted.

At what scale are SRC profitable?

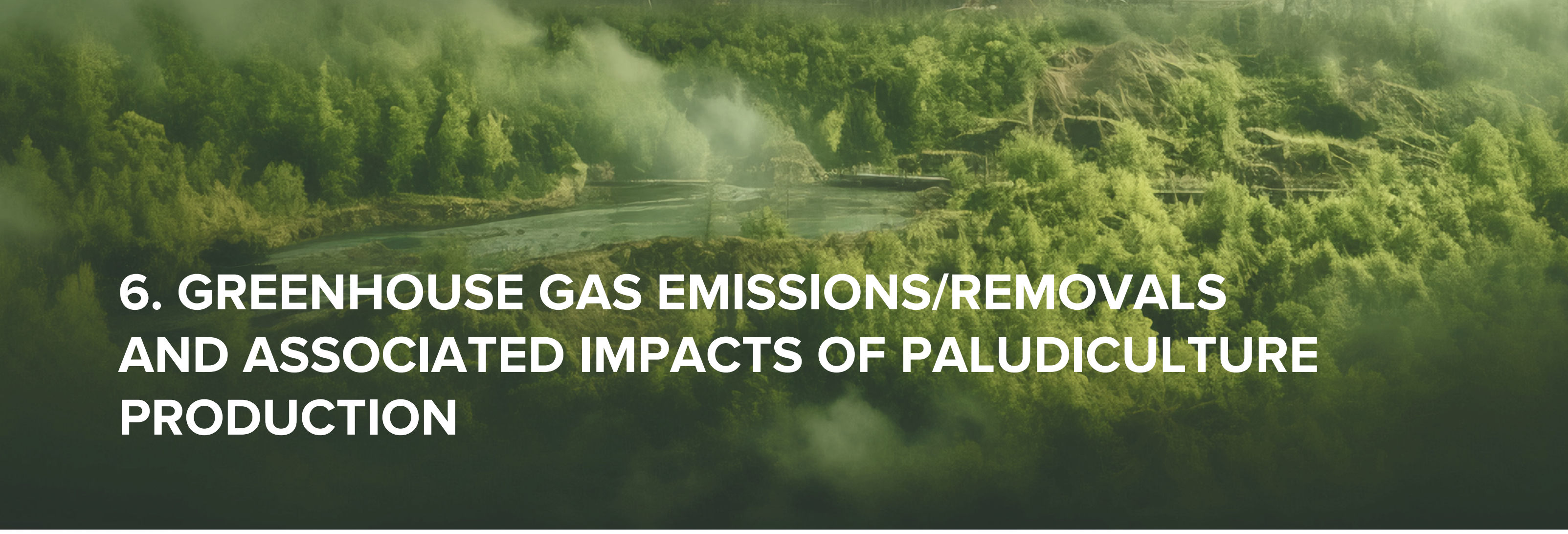
The profitability of SRC depends on many factors. In addition to the yield, harvesting and transport costs are particularly decisive. The greater the distance from the field site to the storage or processing site, the higher the costs incurred.

How does the process affect the greenhouse gas emissions on the site?

In pastures with groundwater levels between 15-45 cm below ground level (water level class 3+), the upper peat layer is permanently aerated. This promotes oxygen-dependent decomposition processes, peatland subsidence and shrinkage. The exact greenhouse gas emissions of these sites under SRC management cannot be reliably determined at present. However, SRC under water level class 3+ can be expected to produce GHG emissions in the order of magnitude of other water level class 3+ practices, while higher emissions can be expected at lower water levels. According to current knowledge, use for SRC plantations only makes sense from a climate protection point of view for (partial) areas where a water level cannot be fully restored at field level.

Table 16.
Average fuel properties for willow SRC.

Lumpiness	P45: 80 % of mass 3.15-45 mm, fine fraction (< 5 %) < 1 mm, coarse fraction (max. 1 %) 63 mm; P100: 80 % of mass 3.15-100 mm, fine fraction (< 5 %) < 1 mm, coarse fraction (max. 1 %) 200 mm
Water content (percentage by weight of moist fuel)	30–60 %
Ash content with foreign content (percentage by weight of absolutely dry fuel)	< 10 %
Calorific value	10–15 MJ/kg



6. GREENHOUSE GAS EMISSIONS/REMOVALS AND ASSOCIATED IMPACTS OF PALUDICULTURE PRODUCTION

6.1 Carbon markets

The introduction of paludiculture reduces greenhouse gas emissions, so the idea of selling these reductions on the carbon market is a good one. Ukraine is not yet a member of the European Union Emissions Trading System, so it can only participate in the voluntary carbon market. But meeting the strict requirements of the Verified Carbon Standard (VCS), "creation" of carbon credits on the voluntary market is associated with high costs. For new project types of peatland rewetting, a methodology must provide details how emissions and emission reductions are assessed. Such methodology must then be verified by at least two independent consultants. The next step is to create a Project Design Document that details the project objectives, estimates of emissions and practical measures. Besides the practical costs of technical implementation, management and monitoring, additional costs arise from independent validation of the project and verification of its results (Joosten et al. 2016a). The strict requirements that guarantee the high quality of the credits imply administrative costs of a voluntary carbon project of several tens of thousands of Euros. Consequently, it becomes prohibitively expensive, particularly for smaller scale projects applying a globally valid standard like VCS. Regional standards like MoorFutures (Joosten et al. 2016a) offer a very good alternative to reduce costs. They usually operate within a fixed set of juridical rules and regulations that need not be assessed independently. Moreover, they address a different market that is far more personal and transparent compared with the anonymous global carbon market. Good regional standards deliver carbon credits of the same quality, but at a considerably lower cost.

6.2 Estimation of direct greenhouse gas emissions and their prevention

Several methods for estimation of greenhouse gas emissions from sites are available. Direct measurements can be done using the eddy covariance technique. Eddy covariance (EC) technique is a direct micrometeorological flux measurement method, which provides exchange rates (fluxes) of energy, gases and aerosol particles at ecosystem scale (from 100 m to 1 km) and high temporal resolution (typically 30-min time step). Among micrometeorological methods, EC is the one with the least assumptions. GHG measurements and evaluations of greenhouse gas balances from these data are rather demanding (Tanneberger and Wichtmann 2011).

Many studies of greenhouse gas fluxes between soil, plant and atmosphere rely on measurements with opaque chambers and additional transparent chambers (see Photos 59 and 60). Different chamber techniques have been developed over the last decades. They allow to make statements about greenhouse gas emissions for a specific type of vegetation (e.g. vegetation form (Succow and Joosten 2001) under the corresponding environmental conditions (e.g. water level). It is sophisticated job to meet the practical and theoretical challenges of measuring soil gas fluxes with non-steady-state chamber systems and to improve the quality of the individual flux measurements and

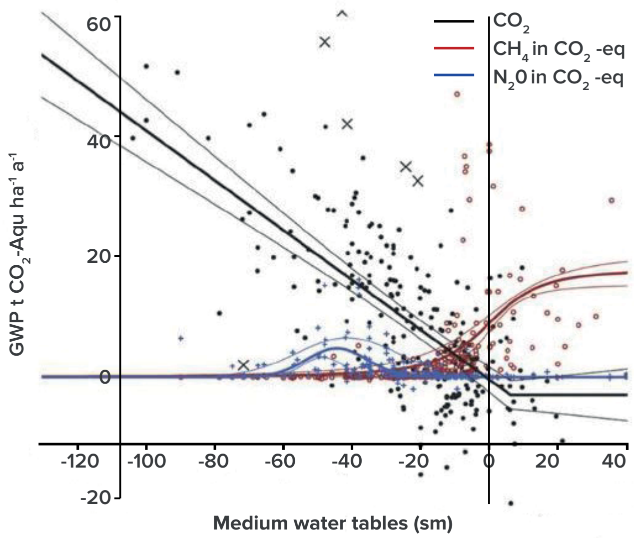
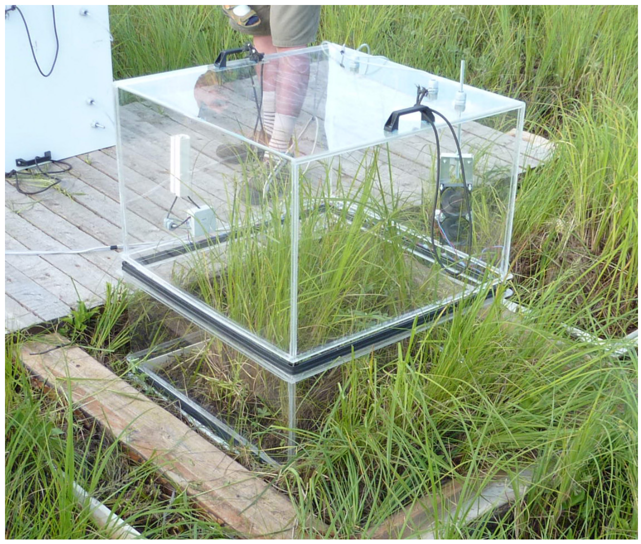


Figure 16.
Greenhouse gas emissions from peatlands at different medium water tables (by Jurasinski et al. in (Wichtmann et al. 2016b), measured by chamber method.



Photos 59 and 60.
Chamber method for measurement of greenhouse gas emissions from vegetated site. Left: A third transparent chamber is adjusted to a stand of common reed; Right: Setup to measure gas exchange in a sedges stand, both photos were made at Yaselda river peatlands, Belarus. (Wichtmann, 2010).

thus entire greenhouse gas studies by reducing sources of uncertainty and error.

In order to be able to make statements about greenhouse gas emissions from an entire peatland, appropriate chamber measurements would have to be made for each individual form of vegetation. That would be very time-consuming, thus, it is simpler to use a proxy[46] for the respective vegetation form or soil moisture class.

Figure 16 shows outcomes from chamber measurements and estimated global warming potential (GWP) expressed as tonnes CO_2 eq. ha^{-1} yr^{-1} based on measurements of CO_2, N_2O and CH_4 against medium water levels. We can see that CO_2 increases with decreasing values for water tables, N_2O seems quite volatile and has its peak at water tables of about -50cm. CH_4 emissions start at about water tables at -10 cm, increasing with increasing water tables. The Figure 2 (Section 2.2) summarizes these charts.

6.3 Indirect measurements – the GEST approach

The “vegetation form” concept (Succow and Joosten 2001) is the basis for the GEST approach (Greenhouse Gas Emission Site Type). It is a classification approach that integrates floristic and environmental parameters. It departs from the observation that in an environmental gradient (e.g. from dry to wet) some plant species occur together, whereas others exclude each other (see Figure 17). The combined occurrence of specific species groups, as well as their mutual exclusion, provides a much sharper indication of site parameters than individual plant species (e.g. the well-known Ellenberg indicator

46 A proxy is a measurable factor that can be used to estimate another factor that is difficult to measure directly.

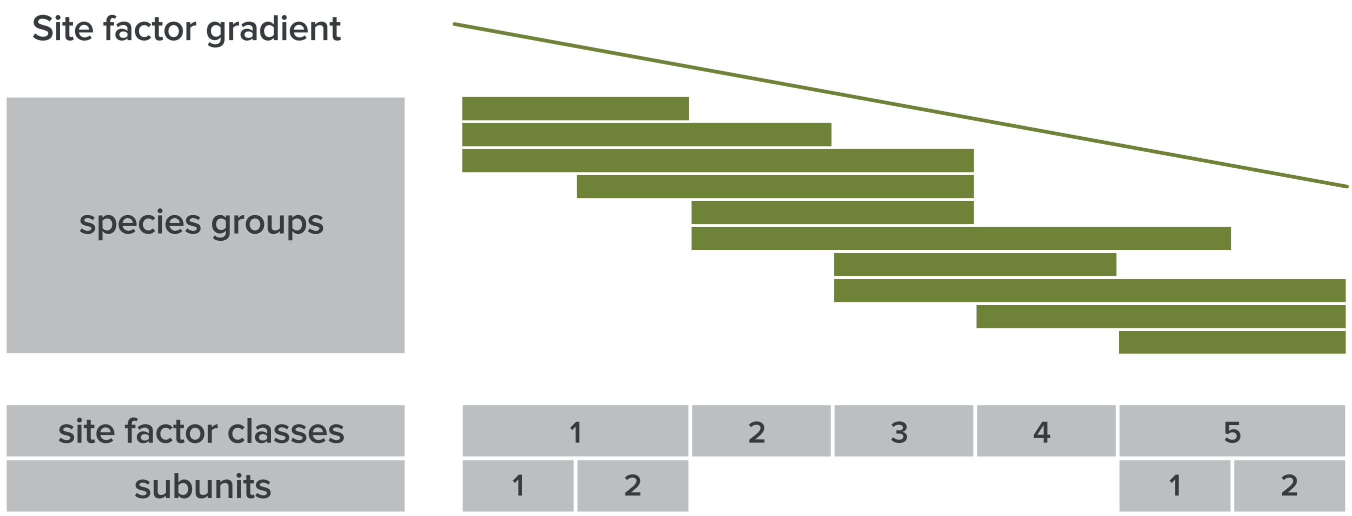


Figure 17.
Co-occurrence of species groups along a site factor gradient

values). The amplitudes of various species groups allow the differentiation of factor classes (see Table 1: Soil moisture classes) according to Couwenberg 2011 in (Tanneberger and Wichtmann 2011).

Vegetation forms are named by the combination of names of characteristic plant species and a term referring to physiognomy and/or type of land use (e.g. Caltha-Filipendula forbs). They can be rapidly identified in the field by checking the presence and/or absence of species groups.

The GEST approach according to Couwenberg 2011 in (Tanneberger and Wichtmann 2011) is based on the site descriptions provided in the literature regarding greenhouse gases (GHG). Vegetation forms were associated with flux measurement sites. For vegetation forms that are indistinct between moist and very moist sites, moist and very moist subtypes were derived based on indicator species or on shifts in dominance. Net CO_2 and CH_4 flux values were assigned to the vegetation forms using the following protocol:

1. Compare the distinguished vegetation types with the vegetational and floristic characteristics described in GHG literature. In case of identical presence and absence of species groups, the GHG flux values from literature are adopted.
2. In order to verify and specify the flux values, compare in a second step the water level data acquired from field observation, vegetation form indication (Succow and Joosten 2001) and Ellenberg values with regression models of GHG fluxes against mean annual water level. In case the water level data do not provide conclusive results, apply expert judgement, taking into account similarities with well documented vegetation types.
3. In case the vegetation does not have sufficient similarity with literature, compare only the water level data and the presence of aerenchymous shunt species with the regression models to arrive at flux values.
4. In case these data do not provide conclusive results, apply expert judgement, taking into account the overall character of the site and its water level conditions and the flux values of related vegetation types.

The GEST approach therefore makes it possible to derive greenhouse gas emissions from a map of the vegetation types of a peatland site, which makes direct measurements, e.g. with the chamber method, unnecessary (Couwenberg et al. 2011).

6.4 Subsidence calculations

Peat loss is the sum of decomposition, wind– and water erosion and settlement of the peat body. A rule of thumb for estimating peat losses from drained peatlands in temperate climates is ~1cm per year. In the tropics, a peatland level loss of several cm per year can also be achieved.

Given the links between oxidation, CO_2 emission and subsidence, CO_2 emissions can be calculated, this can also be used to predict rates of oxidative subsidence. Furthermore, most studies of the relationship between subsidence and CO_2 emission have assumed a constant ratio of oxidative subsidence to compaction, which for temperate peatlands is typically 1:1. If a constant ratio is assumed, then the predicted CO_2 loss can also be used to estimate total subsidence (Mullholland et al. 2020).

Table 17 shows examples of the implemented subsidence model for the sites and paludiculture/conventional crop pairs. The calculator takes the field-level C balance estimate and requires additional user data on the carbon content and bulk density of the soil. This simple model only calculates the extent to which previous rates of subsidence are reduced by a transition to paludiculture management, with a "best case" of zero subsidence in paludiculture systems that are no longer net CO_2 sources. We have not included estimates of the magnitude of surface elevation "rebound" that could occur as a result of rewetting, although it may be possible to add this at a later stage, once we have more data on the relationship between peat surface movement and water table depth change. These data are being collected by the system at a number of sites using a time-lapse camera-based measurement system. Similarly, if some paludiculture systems lead to the re-initiation of active peat formation this could be included in the model, leading to an additional net benefit (Mullholland et al. 2020).

The subsidence calculator has the potential to be used to project future peat surface elevation changes under different land-management options (including higher water level management of conventional arable and horticulture, as well as paludiculture), which have the potential to be linked to other environmental outcomes. For example, the combination of subsidence mitigation and changes in average water table depth could be used to predict changes in future energy costs of pumped drainage based on changes in the relative height to which water will need to be pumped. It could also be used to estimate changes in potential flood water storage capacity and risks to infrastructure (Mullholland et al. 2020).

Paludiculture allows the re-establishment or is connected with new establishment and/or maintenance of ecosystem services of wet peatlands such as carbon sequestration and storage, water and nutrient retention, as well as local climate cooling and habitat provision for rare species. It implies an agricultural paradigm shift. Instead of draining them, peatlands are used under peat-conserving permanently wet conditions. Deeply drained and highly degraded peatlands have the greatest need for action from an environmental point of view, and provide the largest land potential.

Table 17.
Subsidence calculator: Estimated oxidative and total subsidence for a set of theoretical example sites. Bold data are user specified, italic data are taken from the emissions calculator; other data are calculated

CROP	SITE PROPERTIS			SUBSIDENCE		
	C Content %	Bulk density g cm^{-3}	C balance g C m^{-2} yr^{-1}	Oxidative cm yr^{-1}	Total cm yr^{-1}	Mitigation cm yr^{-1}
Paludiculture crop 1			-140	0.00	0.00	-0.33
Conventional crop 1	40	0.3	201	0.17	0.33	
Paludiculture crop 2			-61	0.00	0.00	-0.54
Conventional crop 2	35	0.4	379	0.27	0.57	
Paludiculture crop 3			25	0.02	0.04	-0.95
Conventional crop 3	45	0.25	557	0.50	0.99	
Paludiculture crop 4			112	0.11	0.22	-1.25
Conventional crop 4	50	0.2	736	0.74	1.47	

7. POTENTIAL CO-BENEFITS OF PALUDICULTURE

7.1 Ecosystem services and benefits

Rewetting peatlands and introduction of paludiculture is the only form of land use that offers the potential to utilise the provisioning services of wet peatland sites without significantly impairing regulation services and cultural services (see below). Regulatory services in particular can be significantly improved or restored compared to drained peatland sites through rewetting (Luthardt and Wichmann 2016). The following services are generally associated with a varying degree of wet peatland management (Table 18).

The benefits that can generally be expected from conversion are those that are primarily based on the rewetting measure and the subsequent maintenance of wet conditions, such as the reduction of greenhouse gas emissions, improvement of water quality, flood retention, groundwater recharge and evaporative cooling.

7.1.1 CO_2 emission reduction

Basic considerations for generating carbon credits from peatland rewetting have been summarized already in 2011 (Tanneberger and Wichtmann 2011; Couwenberg et al. 2011). The first carbon credits from peatland rewetting have been sold in 2011 (from the German regional Moorfutures scheme). The first national scheme was implemented in 2017 (The UK Peatland Code); a methodology for rewetting drained temperate peatlands was launched in 2017 under the Verified Carbon Standard (VCS).

Table 18.
Selected ecosystem services of wet managed peatlands (Joosten 2016b)

Section	Group
Provisioning services	• Biomass for nutrition: food and fodder (Närmann et al. 2021) • Plant fibres: construction materials, bedding material, substrates (Nordt and Wichtmann 2024) • Fuel (Eller et al. 2020, (Czubaszek et al. 2021; Wenzel et al. 2022))
Regulating services	• Local and regional climate (Joosten 2016a) • Water purification, retention (in the landscape) (Walton et al. 2020) • Water cycle (Wahren et al. 2016) • Habitat for specialised species[47] (Tanneberger and Kubacka 2018)
Cultural services	• Aesthetic perception and inspiration, physical and mental rehabilitation, green tourism in the bogs (Joosten 2016a) • Information and scientific findings: processes, archives (preservation of remains from organic pollen to human mummies in the thickness of peat bogs) (Joosten 2016b)

47 species that inhabit a narrow range of habitats and/or have a limited diet

7.1.2 Biodiversity

Effects of harvesting on biodiversity has already been described in section 2.4 (Other effects of rewetting of peatlands and conversion to paludiculture). In the past, rewetting was carried out mainly for the restoration of biodiversity. Untouched peatlands rightly served as a reference (van Dijk et al. 2007; Klimkowska et al. 2007). The biodiversity of rewetted, mown or grazed paludiculture fens should, however, not be compared with that of near-natural fens. Rather, the status prior to rewetting, mostly intensively used grassland or arable land, should be used for comparison. In Eastern-European countries, these are also peat extraction sites in fens, and, as a rule, intensively used grassland. Large-scale drainage from the 1960s onwards led to the extinction of fen mire biodiversity typical of Central Europe (Succow and Joosten 2001). The drained fens are intensively used as grassland and arable land and are of low ecological value (Klimkowska et al. 2010). Rewetting and cessation of high-intensity land use will certainly lead to a significant improvement in the condition of wetlands and their biodiversity compared with the current status.

Biodiversity conservation may benefit from paludiculture, but, as paludiculture is a relatively new concept, research on how biodiversity responds to paludiculture is scarce. A multi-taxon study investigating vegetation, breeding bird and arthropod diversity was conducted at six rewetted fen sites dominated by Carex or Typha species. Sites were either unharvested, low– or high-intensity managed, and were located in Mecklenburg-Western Pomerania in Northeastern Germany. It could be shown that paludiculture sites can provide biodiversity value even while not reflecting historic fen conditions. Managed sites had high plant diversity, as well as red listed arthropods and breeding birds. This study demonstrates that paludiculture has the potential to provide valuable habitat for species even while productive management of the land continues (Martens et al. 2023).

Whereas evidence for plants and birds is available from various studies, invertebrate taxa and other organism groups have been insufficiently studied so far. A major information deficit is also seen in the potential effects of wet pastures and cattail cropping paludiculture on biodiversity. Generally, the studies to date have largely investigated either rewetting or management of fen sites. However, both processes must be considered together in the case of paludicultures, and we provide such a combined insight applicable not only to Germany, but also to other temperate fen peatlands in Europe. Biodiversity monitoring should be carried out on all paludiculture demonstration sites, and wherever possible be compared with the status prior to rewetting.

A literature review (van de Poel and Zehm 2014) examines threats to animals due to mowing and suggests ways that these threats can be mitigated. To reduce the impact of mowing on animals, we have several options. The most effective of these include avoiding mowing in a certain area and/or at a certain time. This can also be maintaining strips of old grass, rotating fallow land, reducing the number of mows per year and delaying the first mowing date. Mowing from the inside of the meadow toward the outer boundary – a method which drives animals into refuge areas near the border, is easy to implement and highly effective. The goal should be to drive over as little of the surface area as possible by increasing or standardizing the mower width. This parameter has already had a significant influence on the probability of survival of the animals. Bar mowers are preferred and, in general, the use of conditioners should be avoided. Mulching is not an appropriate substitute for mowing. The cutting height should be minimally 10 cm, or preferably more. The mown material should be neither tedded nor raked and, at earliest, it should be loaded on to the trailer one day after mowing. Following these rules when mowing can ensure the survival of a population (van de Poel and Zehm 2014).

Van de Poel and Zehm (2014) provide a rough overview of the options for protecting different species groups by adaptation of management activities, e.g. mowing. In specific cases, individual measures can then be adapted to the needs of the individual species. For example, alternating early and late mowing is necessary for the re-development of aquatic warbler (Acrocephalus paludicula) habitats in mostly nutrient-rich fens. Other customised management options may need to be developed and implemented for other target species and other site conditions. Therefore, it is necessary to develop a concept before starting work that will include various goals of rewetting measures. If, for example, the measure aims to provide space for biodiversity typical of the peatland site including specific species, the management should be adapted accordingly to their requirements (time of mowing, mowing technique, cutting depth, etc.).

As a result of increasing paludiculture activities, annually harvested reed cultivation areas for the production of thatching material could be created in Northern Germany, providing possible habitats for specialised reed dwellers. In order to assess their habitat potential for reed-breeding songbirds, a breeding bird survey was carried out as well as a literature review on the effects of commercial winter reed cutting on these specialised reed dwellers (Zitzmann 2023). Annual cutting of reed has a significant negative impact on reed-breeding songbirds. Species that depend on older reedbeds (Savi's warbler (Locustella luscinioides), bearded tit (Panurus biarmicus), sedge warbler (Acrocephalus schoenobaenus)) avoid recently harvested areas. However, even the less demanding species, such as reed warbler (A. scirpaceus) or reed bunting (Emberiza schoeniclus), colonise reedbeds in the year after harvesting only in comparatively low densities. Therefore, annually harvested reed cultivation areas as part of paludiculture will not create high-quality habitats for reed-breeding songbirds. Nevertheless, these crops offer multiple opportunities for both farmers and bird conservation. Reed cultivation areas could also reduce the pressure on natural reedbeds, so that species protection and nature conservation objectives can be pursued there primarily. In addition, measures can be integrated into reed cultivation areas to improve their habitat quality for reed-breeding birds. Farmers could be financially rewarded for their implementation, for example by means of agri-environmental schemes. In the context of large-scale rewetting measures, different types of paludiculture and the restoration of degraded (semi-)natural habitats could be combined so that typical biodiversity and fens as a whole would be promoted (Zitzmann 2023).

Paludiculture may also support typical peatland biota, as has been demonstrated for species rich fen vegetation and an endangered aquatic warbler in Poland (Tanneberger and Kubacka 2018). Especially when mowing does not take place annually and parts of the sites are left unmanaged, creating a mosaic of species, harvesting of fen biomass can benefit invertebrate and bird conservation.

Using wet peatlands for buffalo grazing may create a more heterogenous soil and vegetation structure, benefit plant diversity, provide reproduction habitats for amphibians and improve – in combination with late mowing – habitat conditions for endangered meadow-breeding birds. As buffalo hardly need medication, their dung is not contaminated by anthelmintics and support abundant microflora and fauna, which form the basis of a rich food web (Joosten et al. 2016).

7.1.3 Recommendations for enhancing biodiversity with paludiculture practices and fair remuneration

The intensification of agricultural practices in recent decades has led to a substantial loss of biodiversity in the agricultural landscape. Tanneberger et al. 2022 have shown that rewetting of drained fens and implementation of paludiculture is very likely to enhance fen biodiversity compared to the previous drained condition. The following measures should be applied as standard in paludiculture in order to avoid stepping into the same pitfalls conventional agriculture has stepped into in the past (Närmann et al. 2021):

- Abstain from nitrogen or phosphate fertilisation
- Abstain from insecticides
- Abstain from tillage and turning of the soil
- Design and maintain ditches in a way to enhance biodiversity.

To enable the full potential of biodiversity restoration and conservation, biodiversity-promoting measures in wet fen management can be pursued. Such measures can both enhance positive effects and mitigate inhibiting factors. Possible measures in paludiculture include the following (Närmann and Tanneberger 2021):

- Establishment of 1-year rotational fallows,
- No rolling, dragging and harrowing in spring before mowing,
- High cut of at least 8 cm,
- Use of cutting (oscillating) instead of rotating mowing technology,
- Restrictions during bird breeding time.

7.2 Economical aspects of paludiculture

Measures to promote biodiversity often incur additional costs that need to be met. If we want the ecosystem services of wet peatlands and paludiculture to benefit society, we need to develop a system of rewards, not just cost recovery. Producers must see their own advantage in peatlands providing ecological services. In the end, wet peatland management is only interesting for the farmer if the sum of revenues (biomass sales, payments for greenhouse gas emissions reduction, and agri-environmental support) significantly exceeds total costs (see Figure 18). A long-term prospect of substantial net income for the farmer is a prerequisite for large-scale implementation.

Payments for ecosystem services may consist of:

- Payments for maintenance/development of biodiversity
- Remuneration for reduction of nutrient emissions
- Avoiding greenhouse gas emissions and carbon sequestration
- Other services (local cooling, water retention).

Scenario A (Figure 18) shows that reed production can be economically viable in EU countries without external sources of income, while Scenario B (biomass for energy production) requires additional input from external sources. Nevertheless, in Scenario A, additional payments, e.g. for the avoidance of emissions, are to be welcomed.

For many forms of paludiculture, there are still data gaps with regard to costs and revenues. Even for the relatively widespread wet meadows, where much detailed information is available, there is still a lack of information on which site conditions and biomass yields are most frequently encountered on paludiculture sites in practice. Yet, site conditions and characteristics like area size, firmness of the soil, unevenness of the soil, frequency of obstacles and distance from the farm in combination with biomass yields determine the machinery that can be used, the necessary labour input, and the resulting costs and revenues. Therefore, several scenarios should be reviewed. Point estimates of profitability are easily calculated, and deterministic accounting using fixed values is restricted to specific cases. Simulations demonstrating the conditions and the possible range of loss or profit are likely to provide a more accurate picture of reality (Wichmann 2017). Also, potential income from agri-environmental schemes substantially affects the outcome, and future funding frameworks need to be considered carefully (see Figure 18).

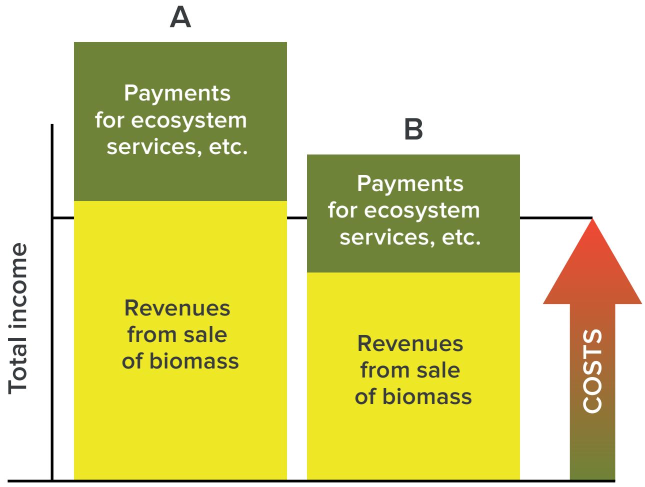


Figure 18.
Assessment of economy of paludiculture by combination of different sources for income generation by paludiculture.
A: Assessment of reed production for biomass;
B: Assessment of production of biomass for energy

7.3 Effect of rewetting and introduction of paludiculture on the health of community residents

Pristine and rewetted peatlands contribute to human well-being by lowering the risk of fires, regulating water supply and offering alternative livelihoods. In areas where peatlands are extensively drained, frequent fires threaten public health and the economy. Supply of drinking water in catchments dominated by peatlands depend on the management of these ecosystems. The aesthetic and recreation values from peatlands and associated wetlands offer opportunities for regional income from ecotourism.

Fires in spring of 2020 went through a lot of drained peatlands and have covered 23% of the territory of the Chernobyl Radiation and Ecological Biosphere Reserve and thus have destroyed 12,000 ha of the forests (predominately plantations) and have damaged 3,500 ha of the peatlands. These fires have proven the vulnerability of the anthropogenic changed ecosystems and demonstrated high risks of remobilisation of radionuclides in areas with radioactive contamination. The fires, originated outside the Chernobyl Exclusion Zone, by mid-April 2020 spread to close proximity of a radioactive waste management zone. Fires not only have increased air pollution (including radionuclides) on the spots, but also affected regional air quality. In fact, due to the fires, ambient air pollution in Kyiv has reached value of 380 (U.S. Air Quality Index) in April 2020, going beyond the threshold of "hazardous" level of 301. Russian invasion in 2022 has caused a new series of fires on the drained peatlands including the territory of the Chernobyl Exclusion Zone. From 24 February 2022 to 31 March 2022, more than 10,000 ha has burnt[48].

7.4 Gender aspects of paludiculture

Both women and men are involved in agriculture globally, although their roles differ significantly by region and are changing rapidly. This applies to wetland management as well. Gender shapes access to productive resources and opportunities, with women having less access to many assets, inputs, and services. Gender studies on peatland utilisation are rare.

In Ukraine, according to statistics, men make up 71 percent of all formal employment in agriculture, forestry and fisheries. Women are underrepresented in managerial and senior positions, compared to clerical and support work. The gender pay gap in agriculture is narrower than the economy average, but at the same time, a significant part of agricultural work, including work typically performed by women, is carried out in the informal and unpaid sectors (FAO, 2021).

While the broader agricultural landscape is marked by a gender gap, the organic sector demonstrates a more equitable distribution of roles and responsibilities between men and women. According to statistics, as of early 2021, women managed 20.8% of farms in Ukraine. And according to a recent study, about 27% of organic farm managers are women. This difference with traditional agriculture can be explained, among other things, by the fact that organic farming is often started by people who do not have inherited traditional stereotypes and instead learn modern methods of farming and business (Organic Initiative, 2024).

In the near future, the post-war reconstruction of Ukraine will largely depend on women, as it must take into account many aspects, in particular, the implementation of the European Green Deal, which is directly related to the participation of women, who are the driving force of green transformations (Organic Initiative, 2024).

The FAO recommendations for improving the situation, appropriate for paludiculture, include the following (FAO, 2021):

- While supporting programs aimed at the economic empowerment of women living in rural areas:
    - Create decent work (paid jobs in the formal sector) for women in agriculture and non-agricultural sectors of the economy. Strive to diversify employment opportunities for women in rural areas and reduce the gender pay gap.
    - Increase support for women farmers and women who want to engage in entrepreneurial activities in rural areas (both agricultural and non-agricultural). The support can include financial and legal assistance, as well as capacity building to enhance women's entrepreneurial skills and address knowledge gaps.
- While increasing the visibility of women and the role of women in agriculture:
    - Follow national priorities in combating gender stereotypes, use opportunities to promote the image of the "female farmer in Ukraine" and women in other professions related to agriculture, and raise awareness of the opportunities of women in rural areas, as well as their vulnerabilities.
    - Engage male leaders and stakeholders in efforts to overcome gender stereotypes, especially in sectors related to agriculture and rural development.

Since drained peatlands are usually land in use, peatland rewetting and implementation of paludiculture will affect land use and livelihoods. Initiatives on peatlands that are excessively wet and

48 https://mepr.gov.ua/informatsiya-pro-naslidky-dlya-dovkillya-vid-rosijskoyi-agresiyi-v-ukrayini-24-lyutogo-18-bereznya-2022-roku-2

have not been drained before can be found also in Ukraine (see Section 1). In some villages, the local economy is enriched on collecting berries from natural peatlands. Here, sustainable harvesting of peatland products that does not degrade the peatland is a potential livelihood opportunity. For climate protection, the protection and restoration of peatlands is a particular priority.

To address several peatland-related challenges, (Ziegler et al. 2021) suggest looking at the role that peatlands play in ensuring livelihoods, varying from a global role to a unitary role in everyday life, to link paludiculture with people's needs and increase their motivation for the development of this area. Paludiculture must be seen as the productive niche within a culture of living sustainably with peatlands (Ziegler et al. 2021).

8. POTENTIAL IMPACTS OF CLIMATE CHANGE ON PALUDICULTURE

There is a certain amount of research on the impact of climate change on paludiculture. Different scenarios imply threats as well as potential challenges and opportunities of climate change for paludiculture. It can be assumed that a redistribution of precipitation will take place in Ukraine, summers will become drier and there will be a need for a large amount of water. That means that the water storage capacity of peatland sites should be optimised. Water from heavy rainfall events must not be drained away directly, but should be stored on the surface onsite. This creates reserves that can then be utilised during the growing season. it can be assumed that this is only possible with a full inundation of 30 to 60 cm in early spring time in order to be able to maintain average water levels of higher than -20 cm below ground level during the summer dry phases. Warmer conditions may induce higher productivities of paludicultures. It is also possible that opportunities could arise for the cultivation of new wetland crops that were previously unsuited to the Ukraine climate. If areas of paludiculture can be designed to store excess river water during winter could provide flood protection to farmland and urban areas, but release water to farmland as required during summer months (Mullholland et al. 2020).

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Barriers to transition

There are a number of reasons that make it difficult to implement paludiculture:

Loss of value of land: Despite all the disadvantages of draining peatlands, they are still considered more valuable by citizens than rewetted ones.

Costs of conversion: The reorientation of peatland use for rewetting and the establishment of paludicultures can only take place after planning and technical implementation. This also includes the purchase and maintenance of specialised machinery. All these steps take time and cost money. Maintaining drainage-based management is often the more cost-effective alternative as long as no emission rights have to be acquired, for example.

Missing markets: Markets for the biomass produced in paludiculture, or the products made from it, can only develop in parallel with the growing supply of these products (hen and egg problem). The easiest way to do this is by replacing less environmentally friendly products with paludiculture products in existing markets.

9.2 Incentives for transition

On the one hand, the state can create framework conditions that provide incentives for the rewetting and implementation of paludicultures (e.g. agri-environmental programmes like payments for ecosystem services from paludiculture, market incentive programmes, introduction of carbon markets etc.). An additional incentive could be the replacement of environmentally harmful products (such as polystyrene insulation boards) with environmentally friendly ones (insulation boards made of typha or reed). Alternatively, private sector initiatives can provide appropriate incentives (e.g. private market for CO_2 emission reduction certificates).

Individual economic interest is at the forefront of any form of decision on management of wetlands and of any thinking of landusers to change something. The production function of a peatland, at the end the price for products from the cultivation and harvesting of special crops (reeds, mosses, drosera) will become:

- Remuneration for nature conservation
- Payments or premiums for ecosystem services

International trade of products from paludiculture may also be decisive. The export of products from paludiculture may be much more interesting than local markets (e.g. export of pellets or thatch).

Some tools/funds for financing peatland rewetting and paludiculture are as follows:

- Moorfutures MoorFutures – Klimaschutz trifft Biodiversitat – Home
- NABU Klima+ approach Moorflachen nass bewirtschaften – NABU
- AECO Schemes aeco – Peatland restoration
- AAA_GDNK-Groen-Veenweide-002-1-english_def_def.pdf (nationaleco2markt.nl)

For example, to apply for the NABU Klima+ approach, the following steps will have to be taken (similar to AECO, which plans to enter the Ukrainian market):

1. Application by land-owner or land-user
2. Prognosis of emission reduction potential by raising water tables
3. Mapping the site following GEST approach
4. Contract
5. Payments for reduction of greenhouse gas emissions

Certification of products from paludiculture can give some additional incentives for switching to more sustainable peatland management to land owners. Within a certification process, a logo can be given to products which comply with the paludiculture principles (see Section 3.1). This gives information e.g. on environmentally friendly production and may reason higher prices than those for not certified products. For this purpose, an organisation must be enforced which manages the process and organises controls and issues certificates to products. A powerful incentive could be the launch in Ukraine of a system for distributing greenhouse gas emission permits, which are granted, for example, to farmers working on drained peatlands, the price of which is increasing every year. An agricultural enterprise would then have to pay a fee for every tonne of GHG emissions. With increasing prices, this would make drainage-based peatland management unattractive and encourage producers to manage their peatlands under wet conditions, i.e. to switch to paludiculture.

9.3 Contribution to Ukrainian reconstruction and recovery

Development of paludiculture in Ukraine will promote the implementation of the following principles of the Green Recovery of Ukraine, which was proclaimed by the Ukrainian NGOs in 2022:

1. Integration of environmental and climate policy into all sectors, including contribution to decarbonization of the agricultural production, biodiversity conservation and transition to sustainable agricultural practices.
2. Reconstruction should serve the needs of Ukrainians and promote the sustainable development of Ukraine. Incorporation of the full cycle of paludicultural production into the national economy will contribute towards development of high added-value production chains, for example production of the insulation materials. Furthermore, enhancing techniques of looking after the natural plantations of berries and herbs growing on the natural peatlands will contribute towards long-term sustainability of the livelihood of the local communities and biodiversity conservation.
3. Adherence to European environmental planning tools for Ukraine's restoration. On 17 June 2024, the EU Parliament has adopted a new law on nature protection. It also includes restoring drained peatlands under agricultural use, so paludiculture is an optimal decision to combine peatlands rewetting with continuous agricultural production.

It is also worth mentioning that paludiculture development in Ukraine will lead to the sustainable and decentralised agrarian systems, which will support the local communities.

9.4 Prospects for paludiculture

If we follow the requirements set by the climate targets, paludiculture does not allow half measures to be taken. But people always try to optimize and improve the economic situation. As wetland plants often have a large amplitude for optimal growth eventually higher yield could be produced with lower water tables.

In addition, lower water tables allow using conventional machinery for harvesting, and no investment in adapted machinery would be necessary. This may lead to weak implementation of the water level elevation e.g. by installation of subsurface irrigation or too low damming targets during construction. Mean water tables should be higher than -20 cm from the soil surface during the summer season, in winter they should be even higher. These seem to be good conditions for many kinds of paludiculture plants (green circle in Figure 19).

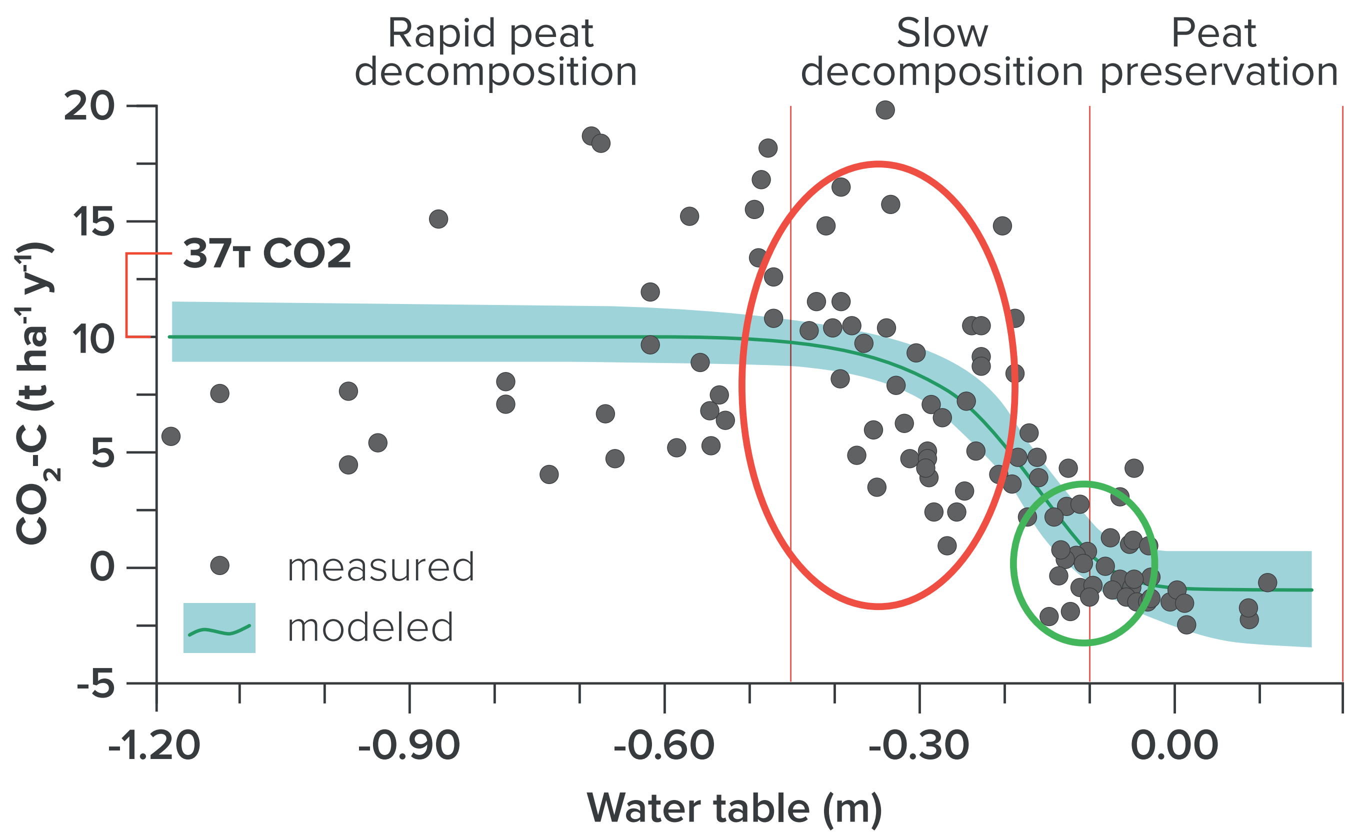


Figure 18.
CO2 emissions from organic soils in temperate zone (modified from Tiemeyer et al. 2020)

Another argument in favour of implementing a slightly lower water level could be that under such conditions, farmers and landowners can accustom themselves stepwise to peatland re-wetting, which will not be very different from normal land management.

Then additional rewetting steps would be necessary to reach the goal of paludiculture at such peatlands. However, a multi-stage approach can be tedious, as the farming practices are oriented towards long time periods (e.g. 25 years) and they cannot turn with the wind. To avoid such problems, a regular monitoring of compliance with the framework conditions demanded by paludiculture must be installed.

There is no need to deviate from the requirements of paludiculture, which always represents a combination of maximum emission reductions and the production of biomass, with regard to the water levels actually achieved. These must be at least -10 cm or higher in winter and -15 cm in summer. Otherwise the ecosystem service "biomass production" would outcompete the emissions reduction and other functions related to peatlands.

Keeping domestic animals in rewetted peatlands can only be the second-best solution for wet peatland management. Only a few selected animal species are suitable for paludiculture (water buffalo, geese and ducks). However, it can be assumed that the keeping of these animal species is not possible on a large scale, but can only be recommended as a niche use, not least due to the lack of expected profitability or the limitation to solutions that involve direct marketing of the products.

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Annex 1:

Extract from the State Register of Plant Varieties Suitable for Distribution in Ukraine

	Botanical taxon (in English)	Botanical taxon (in Latin)	Variety name	Patent	Country of origin of variety
1	White willow	Salix alba L.	H1		UA
2	Crack willow	Salix fragilis L.	A3		UA
3	Crack willow	Salix fragilis L.	Adam		
4	Crack willow	Salix fragilis L.	Adam2		UA
5	Crack willow	Salix fragilis L.	Evangeline		UA
6	Crack willow	Salix fragilis L.	Kozak		UA
7	Osier willow	Salix viminalis L.	Wilhelm	®	SE
8	Osier willow	Salix viminalis L.	Zbruch	®	UA
9	Osier willow	Salix viminalis L.	K2		UA
10	Osier willow	Salix viminalis L.	Katia		UA
11	Osier willow	Salix viminalis L.	Linnea	®	SE
12	Osier willow	Salix viminalis L.	M1		UA
13	Osier willow	Salix viminalis L.	M2		UA
14	Osier willow	Salix viminalis L.	M3		UA
15	Osier willow	Salix viminalis L.	Marciana	®	UA
16	Osier willow	Salix viminalis L.	Panfilska 2	®	UA
17	Almond willow	Vitis L.	Panfilska	®	UA
18	Almond willow	Vitis L.	Yaroslava	®	UA
19	Scots pine	Pinus sylvestris L.	BG 6	®	UA
20	Poplar	Populus L.	Max-4		UA

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