Biomass from wetland buffer zones

- utilization and recycling options.

Technical literature review for CLEARANCE project.

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1 Introduction

Climate change, depletion of resources, and pressures on the environment have forced the European Union to revise its policy towards the sustainable development of economy, i.e., through the support of a circular and low carbon economy in rural areas with a central role played by the wise use of biological resources. Sustainable use of Buffer Wetland Zones subjected to these practices may contribute to solving the problem of resource shortages by reclaiming and recycling nutrients (P) and energy.

Almost all the valley wetlands in the European lowlands have a history of low-intensity agricultural use. Extensive mowing and grazing were among the most important types of traditional disturbance and supported the development of open ecosystems distinguished by high botanical diversity and rich fauna. Therefore, in the management of non-forested ecosystems e.g., wetlands, an introduction of measures aimed at reproducing the former landscape with characteristics species composition is the most common prescription. There is neither a scientific nor a legally unambiguous definition for the term "landscape management" (Sauter et al. 2013). The terms "landscape management" and "nature conservation" are usually used together in order to emphasize the ecological-functional and cultural dimensions of nature conservation simultaneously. The landscape management perceived in that way should enhance:

- biodiversity and functionality of the environment,
- regenerative capacity and sustainable use of natural resources
- diversity, character, and beauty, as well as the recreational value of nature and landscape, are permanently secured "(Sauter et al. 2013).

At present, a limited alternative uses of biomass harvested in extensively managed near stream riparian wetlands as well as watercourses are generally supportive for its use for raw material extraction or energy generation. Therefore, direct competition from any material use or processing into food or feed is considered to be low. Moreover, since landscape management often supports nature conservation objectives, a high level of social acceptance is to be assumed for the utilization of biomass. The use of residual biomass for the generation of bioenergy and biomaterials is often suggested as an element of strategy to avoid negative consequences associated with energy biomass production (Pfau et al. 2019) and is recommend to policymakers Dornburg et al. (2010). Landscape residues include biomass released during vegetation management in various types of landscapes, for example, pastures and semi-natural vegetation in floodplains.

The potential of biomass utilisation is basically characterised by following parameters:

- biomass yield, of which all other potentials are dependent,
- biomass quality, deciding on the possible technical exploitation options
- competitive use, depending on the possible reduction of the base potential
- spatial distribution of the biomass - transport cost factor (Sauter et al. 2013)

Biomass harvested during landscaping and vegetation management could be categorised into two broad groups: woody biomass from forests and shrubs, and grassy biomass from reeds, herbaceous vegetation and natural grassland. The harvested biomass can be used for many purposes, e.g., for thatching (Wichmann and Köbbing, 2015), the production of construction and insulation material (Pude et al., 2005), or energy generation (Köbbing et al. 2013/2014). The conversion technologies of biomass to energy include the production of pellets and briquettes, direct combustion, biocharring and anaerobic digestion (Mills, 2016). Among them, the utilization of wetland plants for biogas generation seems to be a very promising and most sustainable option, delivering energy but and also a digestate, which that can be applied as a valuable organic soil fertilizer rich in C, N, and P. In some cases substantial amount of biomass is left or ploughed on site Pfau et. al (2019).

2 Properties of biomass from landscape management

Biomass from landscape conservation and maintenance works is defined as biomass arising from comprises variety of materials, both woody and herbaceous, that are harvested during maintenance work in nature reserves, landscape protection areas, buffer strips along watercourses, in urban green spaces, public parks, roadsides, hedgerows, etc. The variety of the feedstock is reflected in the range of names: green waste, greenery, landscape management residues. Plant biomass consists mainly of a skeleton of cellulose and hemicellulose, interspersed with lignin (also called lignocellulose). These three substances together usually contain more than 90% of the biomass dry matter (Mills, 2016).

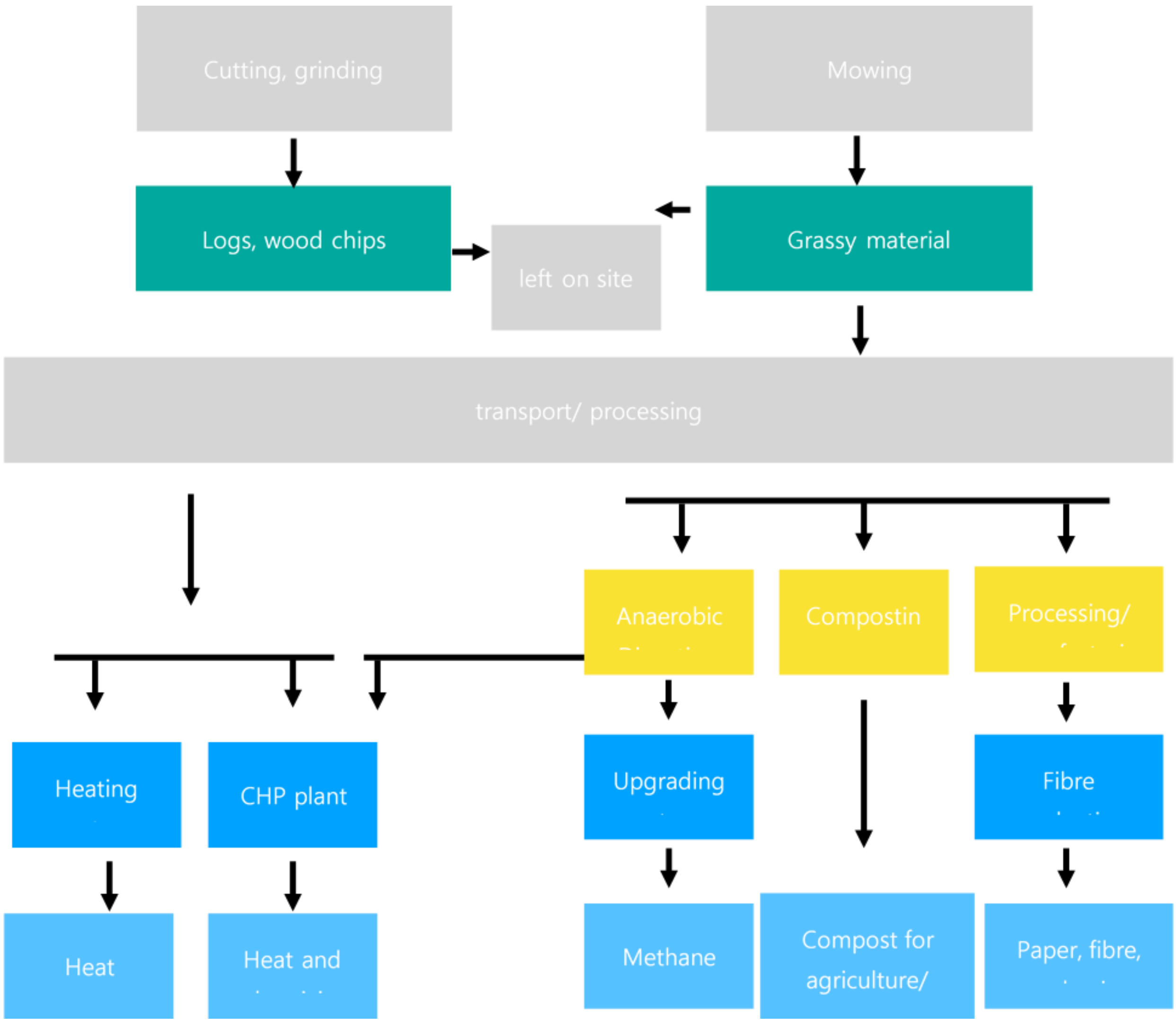

Figure 1 Scheme of biomass utilisation (after Pfau et. al. 2019, changed)

In addition to these biopolymers, biomass contains extractives and ashes. Extractives consist, for example of proteins, fats, fatty acids, resins, and aromatic compounds such as phenols. Ash refers to the inorganic solid that remains behind when the biomass is burned. It consists of nutrients taken up by the plant (silica, calcium, potassium, sodium, phosphorus), pollutants (e.g., heavy metals), or impurities (like soil particles, dust, etc.).

Depending on the area of origin, feedstock has different characteristics, as it is a mixture of herbs, grasses, and woody material. Usually, landscape management material is low in nutrients (low feed value), mostly without application in agriculture. The biomass is also, compared to energy crops, less polluted with pesticides, heavy metals, and pharmaceutical residues.

The timing of biomass harvest determines its quality and possible energy conversion process. However, this factor is, to a great extent, affected by nature conservation objectives and to some extent, weather conditions as well as the accessibility of the land to machinery. Thus, very often, material from landscape management poses special adverse features, which are challenging compared to the commonly used substrates, like energy crops (Sauter et al. 2013).

The origin of the biomass, as well as the timing and frequency of cutting, have a strong influence on its chemical composition, primarily, the proportion of lignocellulosic components. This component is desirable in the case of biomass combustion, but it can be problematic if the biomass is intended for biogas production. Late-cut grass or material from the third or fourth cut has a significantly higher proportion of lignocellulosic components than first or second grass cuttings performed in early summer, and cannot be converted easily during anaerobic digestion. The early mown grass is rich in crude protein, crude fat, and sugar, and is therefore favorable for biogas production and composting. However, if the first cut is made later, at the end of June or the beginning of July, the grass is heavily ligninous. The second crop harvested at the end of August / September is at an earlier stage of development than the first late mown growth. As a result, it has better fermentation properties and can be better used for biogas generation.

Late harvested plants for biogas generation have the C:N ratio mostly below 20:1 or above 30:1, which lays in the suboptimal range. Similarly, the C:N:P ratio departs from the optimum, which should be in the range from 100:5:1 to 200:5:1 (Effenberger and Lebuhn, 2008). Values close to the optimum are food found only for reed canary grass (Roj-Rojewski et al. 2019).

Consequently, the wetland species exhibited rather low methane potential and a modest net energy gain after digestion, which amounted to 23-30 GJ ha^{-1} for the perennial grasses and tall-sedge communities with *C. elata* and *C. gracilis*. For the low-productivity sedge-moss communities, the net energy gain could be extremely low and amounted to 3.5 GJ ha^{-1}.

Another problem is the abrasive properties of the grass from landscape management; this negative feature is enhanced if grass is ensiled, due to its acidic reaction.

Winter harvest, between January and April, is favourable feedstock for thatching or combustion since the moisture content of the material is typically around 15%.

3 Harvesting

The technologies adaptable for biomass harvesting depend on the spatial characteristics of the harvested area. The expenditures of labor and energy for mowing, balling, and transport of the yield to a collecting point at the valley outskirts depended on the net primary production of the plant communities as well as the accessibility (e.g., local inundation and microtopography) of the site. The floodplains and riverbanks are often difficult to access by the conventional agricultural machinery, and as a consequence, often alternative technologies have to be developed, e.g., redesigned alpine snow-grooming machines.

In the Narew River valley, the highest energy input per unit area (EI) for biomass harvest, 1.90 GJ ha^{-1}, characterized the highly productive area distant from the upland: rushes of common reed *Phragmitetum australis* and hardly accessible tall-sedge communities of *C. elata*, with a noticeable hummock and hollow structure. The energy demand for the harvesting of the *Phalaridetum* and *Glycerietum* communities was estimated to average 1.58 GJ ha^{-1}, while the mowing of the sedge moss communities with *C. lasiocarpa* required 1.36 GJ ha^{-1}.

4 Storing / Ensiling

Dry biomass harvested for combustion in heating plants can be successfully stored in the form of bales, similarly to residual biomass from agricultural production. The technology is well known and proven in practice. The material for anaerobic digestion or for the hydrothermal carbonization needs to be ensiled. Ensiling preserves the biomass and ensures continuity of feed for seasons when the biomass cannot be harvested. Ensiling is undertaken to store material in an anaerobic environment. The process must be performed shortly after the harvest when the material is fresh and not left to degrade in contact with the air. If biomass was ensiled effectively, it could be kept for many (up to 3) years. For adequate ensiling of grassland biomass from landscape management, Herrmann et al. (2014) recommend an application of silage additives.

5 Conversion technologies

5.1 Combustion

Combustion for heat appears to be one of the most straightforward technologies of energy generation. Although the process is simple, there are many different technological combustion approaches. The three options are most often used: combustion of “raw” chopped/shredded material, combustion of bales, or combustion after biomass agglomeration to the form of briquettes or pellets (Sauter et al. 2013). The choice depends on site conditions, available machinery, and market/place of combustion. On the other hand, a method of combustion will determine the harvesting, collection, and processing methods that ensure that the material will have the appropriate properties.

For the use of shredded material or pellets, different processing steps of the fuel are necessary, scientifically investigated in the past. Due to higher energy density and good dosing behavior pellets, despite higher production costs, are in high demand, especially for small installations (Vetter and Hering, 2003).

The technical process of agglomeration pelleting/briquetteing encompasses six sub-steps: drying, crushing, conditioning, pelleting, cooling, and screening.

For the chopping of fiber-rich biogenic material, hammer mills and granulators (cutting mills) have become established. In industrial pellet production, hammer mills are mainly used. Feedstock disintegration is key to the agglomeration process. The increased surface area of the raw material enables the better release of the binding compounds e.g., lignin, starch, or proteins, while too large particles in the pellet increase the risk of their breakage.

Pelleting is an agglomeration process, in which pressure compacts fine-grained and fibrous material into a lumpy product of the desired size and features (Sauter et al. 2013).

The main advantages of pellets, in contrast to loose material, include:

- homogeneous size distribution in the fuel bed,
- high energy and bulk density,
- good dosing and flow properties,
- high storage stability in terms of biodegradation due to the low water content,
- very low dust formation during re-loading, packaging and processing.

A major disadvantage is the production costs. However, these are faced with the high transport costs of loose material or bales and make the product more economical.

The economics of four types of pellet production were compared by specialists from Deutsches Biomasseforschungszentrum.

Table 1 Comparison of 4 variants of pelleting plant (Sauter et al. 2013)

Assessment criterion	**Stationary pelleting plant, centralised model**	**stationary pelleting plant, decentralized**	**Wage pelleting stationary**	**Wage pelleting mobile**
Cost per ton of pellets	~86 €	no data	~36 €	~102 €
Investment costs	high	low	low	low
labor demand	medium	high	low	medium
Availability / development status	high	low	high	medium
flexibility	low	high	high	high

- **Stationary pelleting plant, centralised model (variant 1)**
    - Pellet plant is located at a central point of the area, which is well accessible from the regions of origin of the biomass, and is as close as possible to the consumers. Total production of 5,000 t/year and the employment of one employee was assumed. The hay needs no be dried before pelleting.

- **Stationary pelleting plant, decentralized (variant 2)**
    - In this variant, several small pelleting plants are set up in the area. The production should cover the own needs of owners. Due to the low pellet quality, the low production capacity (25 kg /h), and the low automation, the facilities are of limited suitability for commercial production. Since most of operation i.e., feeding the raw material, is done manually, the production is labor-intensive.

- **Pelleting in stationary installation on request / service (variant 3)**
    - Due to the elimination of investment costs and the reduction of personnel costs, this is an exciting alternative. The prices for the production of hay pellets are about 30 € / t. In case the hay would be dried before further processing, the production costs would increase to about 80 € / t.

- **Pelleting in mobile installation on request / service (variant 4)**
    - The main units are mounted on a carrier vehicle. The pellets are produced directly at the heating plant or near the source of feedstock.

The calculation of the pelleting costs of variant 2 (own, decentralized pelleting) has been omitted since this is not suitable for the production of high-quality market products. According to (Sauter et al. 2013) of the three other pelletizing variants, variant 3 has by far the lowest production costs. However, it requires a minimum amount of pelleting. It is conceivable, therefore, that at smaller quantities variant four, and at significantly higher quantities than the estimated 5,000 t of pellets, option 1 is superior.

Challenges

According to the current state of technology, the use of biomass from landscape management for energy production in heating plants is possible. For hay heating plants, experience exists mainly for whole-bale firing with straw bales. In recent years, several systems of this type of firing (usually between 300 and 1,200 kW thermal power) have been installed (Sauter et al. 2013). The results show that good economic viability and high greenhouse gas reduction potential can be expected for certain plant concepts. However, some elements contained in biomass: potassium, chlorine, sulfur, or nitrogen are considered to be problematic, since, in conventional combustion systems, they can lead to slagging and corrosion of installation. Analyses by (Sauter et al. 2013) demonstrated that landscape feedstock collected in floodplain and wetlands receiving mineral and organic fertilizers had an average ash content amounted to ~5% and the calorific value ~17.3 MJ kg^{-1}. Increased ash content up to 8% lowered the calorific value to about 1 MJ / kg. The concentrations of the other elements show substantial variations depending on the origin of feedstock, especially in the case of N (1.2%-1.8%) and K (0.38-2.44%). Content of S in biomass changed between 0.10-0.24%, Cl 0.20-0.86%Burning biomass causes emissions of particulate matter and dioxin / furan that often exceed legal norms especially in small plants (<100 kW) not equipped with appropriate separation technology such as cyclone, electric or fabric filters, flue gas scrubbing etc. In experiment by DBFZ burning hay in a well-regulated oven did not cause excessive emissions of pollutants into the atmosphere, however emission of atmospheric aerosol particles PM, dioxin / furan as well as in some cases the emissions of CO and HCl are of concern.

Combustion tests on hay pellets have shown that slagging and corrosion can be avoided by use of additives, even in the case of small plants, and consequently burn-off behavior can be improved.

5.2 Anaerobic Digestion

Anaerobic digestion (AD) can be used for processing green/ensiled material of higher moisture content to produce biogas, which is then either converted through a combined heat and power plant to produce electricity and heat or fed directly into the gas grid. A main by-product of AD is digestate, which is the residual material post digestion, which and can be used as an organic fertilizer. Due to the properties of grassy biomass from landscape management, the machinery/technology of biogas plants that process this feedstock must be much more robust than those using maize or manure. Feeding technology such as screw conveyors or pumps must be designed significantly more powerful, ie, with a higher diameter of feeding pipes and higher material thickness. The same applies to the stirring technique. Slow-running paddle stirrers are recommended instead of fast running submersible mixers (Ahlers, 2008).

Recent research indicates that landscape management material should be fermented using dry technology. Dry fermentation is best suited for processing organic material with a DM higher than 25%, mainly dry, fibrous, and contaminant-containing biomass, such as biowaste, organic fractions from residual waste, and green waste, which can be problematic in wet fermenting biogas plants. Depending on the process variant, the material is mashed with process liquid before fermentation or sprayed with aqueous liquid during fermentation to facilitate the necessary microbial processes (anaerobic degradation).

In dry fermentation, there are various process variants. The fundamental distinction is made by the division into continuous processes (plug flow fermenter) and discontinuous or batch-wise process (garage fermenter). For continuous processing of substrates in dry fermentation, plug flow fermenters are used. The substrate is conveyed using large hydraulic piston pumps as a "plug" through the horizontal fermenter. Due to the high dry matter content, it is possible to mix the contents of the fermenter only locally and not between the feed and the output. As a result, a minimum residence time of the substrate in the fermenter can be ensured.

In batch mode with regular emptying and refilling, a stackable substrate is used, which is not moistened beforehand. However, the staggered operation of several fermenters on a plant, relatively uniform gas production, can be achieved. The decisive factor in dry fermentation is the inoculation of the newly filled fermenter with anaerobic microorganisms in order to start the degradation under the exclusion of oxygen quickly. The inoculation takes place either by remixing the digestate of the previous batch or by moistening with percolates. During fermentation, exiting liquid (percolate) is collected and fed back to the digestate (fermentation substrate) from above.
Vogel et al. (2009) found dry fermentation of landscape material to be more effective than a combined dry-wet fermentation. Biogas yield in dry fermentation (percolation system
retention time 30 days) amounted540-750 Nl kg^{-1} oDW.

Challenges

For AD plants, the main technical challenge is the processing of lignin-rich substrates. Plants with a high lignin content such as late-mowed grass or reeds are only of limited use for traditional plants and lead to problems in feeding to the fermenter and in gas production. To counteract these disadvantages, sufficiently robust plant components must be installed. The parts should have a low susceptibility to corrosion and be able to guide the substrate into the fermenter without clogging. Besides, it is advisable to process the problematic substrate in a preliminary stage (hydrolysis or mechanical comminution) so that a high gas yield can be achieved in the further course of the process. Under these conditions, the grass is already used in several wet fermentation plants. An exciting alternative may provide DA plants working in dry fermentation technology. However, this technology is entirely new, and only a few plants of such kind are known.

Biogas generation might be a reasonable utilization pathway for grassy biomass from landscape management if the harvest occurred up to late summer. Herrmann et al. (2014) stated that methane yields of biomass decreased from up to 309 lN kg−1 organic dry matter in May to below 60 lN kg−1 oDW in February, and was correlated with increasing crude fiber contents. Among vegetation of Alopecuretum pratensis, Molinietum caeruleae, and Caricetum gracilis, the biomass of Caricetum was the least suitable feedstock. It showed 25% lower methane yields compared to other types of vegetation.

An essential prerequisite for the economic operation of the plant is the extensive use of heat. For biogas plant concepts, it also plays a vital role in achieving the lowest possible greenhouse gas emissions. Heat may be utilized in human settlements and production plants, e.g., in the field of agri-food processing, horticultural and agricultural businesses, etc.

The distribution and size of the potentially available biomass supply, as well as its quality, have a significant influence on the design of usage concepts. The availability of the examined grass and reed assortments, measured on average transport distance, is of great economic importance.

The quality of the substrates used has significant implications for the feasibility and success of the usage concepts. Optimally, substrates of the same class should be fed continuously into biogas plants, so that the individual components can then be tuned. Due to the high degree of heterogeneity and the low quality of the biomass of extensively managed grassland or biotope care, particular demands must be placed on the recovery technologies. Generally, with lower substrate quality, the technical failure risk of the system increases, and the gas yield decreases.

5.3 Composting

Composting is an aerobic process in which microorganisms are involved to convert diverse organic material to a relatively stable and pathogen-free end-product (Wagner and Illmer, 2004)
Experiment by Toumpeli et al. (2013) on the composting of *Phragmites australis* Cav. alone or with animal manure demonstrated excellent properties of obtained products. Compost pH was neutral, and the C:N ratio was in the range from 43.3 for the mature reed to 22.6 for young reed. They also found a positive influence of compost on the properties of soil and the improvement of plant growth.

5.4 Hydrothermal Carbonisation

The Hydrothermal Carbonisation (HTC) is a new technology that enables the generation of biochar (called hydrochar) from biomass. The process was proved to have good energy efficiency and is well suited for the utilization of different organic residues and waste materials.

The suitability of HTC has been verified for sewage sludge and organic municipal solid waste and implemented within a continuously operating, industrial-sized plants (Buttmann, 2011). Recently, the appropriateness of HTC for processing biomass from landscape management has been suggested by Greve (2016). At temperatures of about 200◦C, water splits off from the biomass. Other byproducts are small amounts of gases (mainly CO_2) and warmth. It has been reported that two-thirds of the original gross calorific value of biomass remains, and up to one-third of the energy was released in the form of heat in the exothermic reaction. Therefore, an HTC reactor would manage after one heating without further external energy supply.

Besides, the range of applications of HTC-char is very large. In addition to energetic utilization, there are versatile ideas for material use (also due to the emerging nanostructures of coal). Of particular interest is the application in the soil to increase their quality while storing carbon.
The recent studies demonstrated that HTC could be successfully applied for processing of lignocellulosic biomass to a peat-like hydrochar, which could be a substrate for alternative organic growing medium.

6 Life Cycle Analysis of biomass use; Greenhouse gases balance

Landscape management practices are adapted for optimal use of residual biomass as an ecosystem service. A feedstock is suggested to be useful for multiple purposes, including energy and material applications. Usually, it is indicated as a solution that is clearly beneficial for the environment. Sometimes, however, it is not obvious, the acquisition and use of biomass can be associated with many-sided impact on various components of the environment. Until now, no formal objective evaluation methods are applied or available. Therefore, the lack of ranking criteria results in a trial and error approach and associated high uncertainty (Bout et al. 2019).

Natural wetlands are considered as a sink for GHG. The average annual sequestration of carbon was estimated at 29 g C m^{-2} yr^{-1} for North American peat peatlands (Gorham (1991), while boreal wetlands can bind 15–26 g C m^{-2} yr^{-1} (Turunen et al. 2002). Mowing and removal of landscape biomass for applications outside of the riparian area may result in carbon and nutrient losses. Biomass decomposes slowly under natural conditions, but most of the management practices result in a rapid release of CO_2.

In the Netherland, Pfau et al. (2019) found that among various utilization processes composting of biomass had the highest GHG emission. Composting for agriculture resulted in the GHG burden amounting to 62 kg CO_2 eq t_{FW}^{-1}. In contrast, all analysed energy applications of biomass provided GHG benefits. They ranged from 132 to 112 kg CO_2 eq t_{FW}^{-1} for woody biomass (combusted for heat and CHP), and from 56 to 0.5 kg CO_2 eq t_{FW}^{-1} for grassy biomass used for generation of biogas and “green gas”. Production of compost for replacing peat as a growing media brought a great GHG benefit amounting -229 kg CO_2 eq t_{FW}^{-1}. Such a high value results from avoiding emissions from dehydrated peat bogs prepared for peat extraction and oxidizing of the growing substrate. However, results may be strongly changed depending on the transport and logistic approach.

Using a grass harvested on riverbanks for anaerobic digestion in Italy (Boscaro et al., 2018) was shown to have a beneficial GHG balance saving equivalent emissions of about 86-67 CO_2 eq t_{FW}^{-1} (233-181 kg CO_2 eq t_{DW}^{-1}), and fossil energy of about 2.6-2.4 GJ t_{FW}^{-1} (7.0-6.4 GJ t_{DW}^{-1})
Hansson and Fredriksson (2004) analyzed three options of agricultural use of Phragmites biomass: chopping and spread it directly on farmland, composting the raw material before spreading, and use the biomass as feedstock for biogas production and spread the digestate on cropland. They concluded that harvesting of reed for biogas production produces both large amounts of energy in the gas and nutrients. The energy balance of the biogas was favorable; however, the economics of the system was sensitive to changes of tariffs for energy supplied to the grid.

The options of direct use of Phragmites as green manure was cheap but produced no useful energy. The production of compost has the least favourable characteristics among the three strategies studied. The energy balances for the three systems were calculated to +4.05, −0.43, and −0.35, MJ kg^{-1} harvested dry matter, respectively. The application of reed compost as a soil amendment probably causes higher total N emission compared to reed digestate and green manure.

Pfau et al. (2019) compared emissions of GHG in different applications of residual biomass harvested during landscape management. They found higher climate benefits when biomass was utilized for bioenergy than for biomaterials.

Properties of biomass harvested in WBZ, after Thrän et al. 2009, changed and expanded

Meadows and grassland on mineral soils in transition areas between cropland and stream valley	
Description	Herbaceous open-land biotopes Permanent grassland, fresh meadows, abandoned wet meadows
Management	1-2 cuts /year (extensive use, first cut for hay), usually 2 (maximum to 5) cuts /year (intensive use), if necessary grazing by domestic animals), removal of encroaching bushes and trees if necessary
Biomass characteristics	
Feedstock	green cut
	Grasses (….), clover, ruderal plants (e.g. nettles), perennials (e.g. cabbage thistle)
Biomass potential	2-8 t_{DW} $ha^{-1}a^{-1}$ 7-20,4 t_{DW} ha^{-1} a^{-1} 4,5-13 t_{DW} $ha^{-1}a^{-1}$
Current use	
Provision / exploitation	Mowing, clearing, removal of biomass • Use as hay or silage, green forage production • composting
Potential concepts of energetic use	
Exploitation	Biogas generation (in particular dry fermentation in batch process)
Conditions /restrictions	• Seasonal substrate supply, ensiling necessary for year-round use • Substrate quality strongly dependent on location and weather • Logistics: costly exploitation of small-scale areas (hand-mowing, bar mower, finger-bar mower), high transport costs, necessary homogenization, cut to smaller particles (silage to a length of 1 to 3 cm), possibly digestion • High DM content is unsuitable for mono-fermentation • Stem (long-stemmed, long fibers) can cause mechanical problems for pumps, agitators (in wet fermentation) • in late cut - high crude fiber content results in lower gas yield
Typical substrate properties	
Dry matter (DW) content	18-30% (meadow grass), 17-20% (clover, clovergrass)

Organic dry matter (oDW); Volatile Solids	90-95% in the DW (meadows, clover grass), 80% in the DW (clover)
Methane content [% by volume]	53-54% (meadow grass), 55% (clover grass), 66% (stinging nettle)
Biogas (methane) yield [$m^3\ t_{oDW}^{-1}$]	550-570 $m^3\ t^{-1}$ (meadow grass), 800 $m^3\ t^{-1}$ (clover), 360 $m^3\ t^{-1}$ (nettles) methane yield 300–450 $m^3\ CH_4\ t^{-1}$ VS *Phleum pratense* L. var. erecta 344 - 383 $m^3\ CH_4\ t^{-1}$ VS.

Wet meadows	
Description	Herbaceous open-land habitats, nutrient-rich, extensive wetlands and wet grasslands
Management	1-2 cuts a^{-1}(extensive use), 1 cut late in the year (purple moor-grass Molinia caerulea), grazing (cattle), removal of encroaching bushes and trees if necessary
Biomass characteristics	
Feedstock	green cut
	Grasses, herbs, with high share of rush Juncaceae and sedges Cyperaceae
Biomass potential	20-25 $t_{DW}\ ha^{-1}\ a^{-1}$ (2-cut, wet meadow) 4-7 $t_{DW}\ ha^{-1}\ a^{-1}$ (1-cut, wet meadow) 1,5-3 (bis 4) $t_{DW}\ ha^{-1}\ a^{-1}$ (1-cut, *Molinietum caeruleae*) 4-9 $t_{DW}\ ha^{-1}\ a^{-1}$ (fresh meadows)
Current use	
Provision /exploitation	• Biomass extraction necessary to maintain nature conservation function • Mowing, swathing, clearing, removal of biomass • extensively used for litter meadows, pasture feed
Potential concepts of energetic use	
Exploitation	Biogas generation (in particular dry fermentation in batch process)

Conditions /restrictions	• Seasonal substrate supply, ensiling necessary for year-round use • Substrate quality strongly dependent on location and weather • Logistics: costly exploitation of small-scale areas (hand-mowing, bar mower, finger-bar mower), high transport costs, necessary homogenization, cut to smaller particles (silage to a length of 1 to 3 cm), possibly digestion • High DW content is unsuitable for mono-fermentation • Stem (long-stemmed, long fibers) can cause mechanical problems for pumps, agitators (in wet fermentation) • in late cut- high crude fiber content results in lower gas yield
Typical substrate properties	
Dry matter (DM)	18-30% (meadow grass), 17-20% (clover, clovergrass) 13-24% (crop, fresh), 75% (crop, dry)
Volatile Solids; organic dry matter (oDW; % of DW)	90-95%
Methane content [% by volume]	55-57% (maximum fluctuation range 42-79%), 84% (hay)
Biogas (methane) yield [$m^3\ t_{oDW}^{-1}$]	biogas 80-150 $m^3\ t^{-1}$ (mx up to 730 $m^3\ t^{-1}$) methane yield 300–450 $m^3\ CH_4\ t^{-1}$ VS *Phleum pratense* L. var. erecta 344 - 383 $m^3\ CH_4\ t^{-1}$ VS).

Reeds (*Phragmition)*		
Description	**reed beds** Phragmition in floodplains, waterlogged depressions, estuaries and stripes along watercourses	
Management	mowing every 2 to 5 years, mosaic winter harvest (extensive use), no maintenance measures in protected areas necessary	
Biomass characteristics		
Feedstock	green cut	
	Reed Phragmites australis, **reed canary grass *Phalaris arundinacea, bulrush Typha sp. sweet canary grass Glyceria maxima,***	
Biomass potential	5-43 (Ø 10-15) $t_{DW}\ ha^{-1}\ a^{-1}$ (reed)	
Current use		

Provision / exploitation	• Phalaris and Glyceria are used for fodder • Reed - production of reed mats (insulation and wind protection, roofing material; use as an alternative to wood pulp extraction discussed
Potential concepts of energetic use	
Exploitation	Biogas generation (in particular dry fermentation in batch process)
Conditions /restrictions	• Seasonal substrate supply, ensiling necessary for year-round use • Substrate quality strongly dependent on location and weather • Logistics: costly exploitation of small-scale areas (hand-mowing, bar mower, finger-bar mower), high transport costs, necessary homogenization, cut to smaller particles (silage to a length of 1 to 3 cm), possibly digestion • High DM content is unsuitable for mono-fermentation • Stem (long-stemmed, long fibers) can cause mechanical problems for pumps, agitators (in wet fermentation) • in late cut - high crude fiber content results in lower gas yield
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Biogas (methane) yield [$m^3\ t_{oDW}^{-1}$]	biogas 80-150 $m^3\ t^{-1}$ (mx up to 730 $m^3 t^{-1}$) methane yield 300–450 $m^3\ CH_4\ t^{-1}$ VS

Sedges (*Magnocaricion*)		
Description	floodplains, waterlogged depressions, estuaries and stripes along watercourses	
Management	Cut every 2 to 3 years late in the year (from the end of September), "occasionally grazed" (extensive use	
Biomass characteristics		
Feedstock	green cut	

	Sedges, rushes, mosses, wool grasses
Biomass potential	1-2 (up to 2,5) t_{DW} $ha^{-1}a^{-1}$ 9-14,3 $t_{FW} ha^{-1}a^{-1}$ 3-9,9 t_{DW} $ha^{-1}a^{-1}$
Current use	
Provision / exploitation	• Biomass extraction necessary to maintain nature conservation function • clearing of shrubbery, grazing, extensive use of hay • Mowing, swathing, turning, clearing, removal of biomass • Composting
Potential concepts of energetic use	
Exploitation	Biogas generation (in particular dry fermentation in batch process)
Conditions / restrictions	• Seasonal substrate supply, ensiling necessary for year-round use • Substrate quality strongly dependent on location and weather • Logistics: costly exploitation of small-scale areas (hand-mowing, bar mower, finger-bar mower), high transport costs, necessary homogenization, cut to smaller particles (silage to a length of 1 to 3 cm), possibly digestion • High DW content is unsuitable for mono-fermentation • Stem (long-stemmed, long fibers) can cause mechanical problems for pumps, agitators (in wet fermentation) • in late cut: high crude fiber content results in lower gas yield
Typical substrate properties	
Dry matter (DW)	30-37 % (Mähgut, Segge)
Volatile Solids; organic dry matter (oDW; % of DW)	90-95%
Methane content [% by volume]	~50%
Biogas (methane) yield [m^3 t_{oDW}^{-1}]	biogas 80-150 m^3/t (max up to 730 m^3/t) methane yield 300–450 m^3 CH_4 t^{-1} VS

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