Harvested meadows along lakes

A possible biomass resource with benefits for climate and biodiversity

Master's thesis in Industrial Ecology

EBBA MAGNUSSON
REBECCA WATKINS

DEPARTMENT OF SPACE, EARTH, AND ENVIRONMENT

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023-05-25
www.chalmers.se

Harvested meadows along lakes – A possible biomass resource with benefits for climate and biodiversity.

Supervisor: Christel Cederberg & Göran Berndes, Department of Space, Earth and Environment

Examiner: Göran Berndes, Department of Space, Earth and Environment

Master's Thesis 2023

Department of Space, Earth and Environment

Chalmers University of Technology

SE-412 96 Gothenburg

Telephone +46 31 772 1000

Cover: Photo of overgrown lake Tydjesjön, Sweden

Gothenburg, Sweden, 2023-05-25

Harvested meadows along lakes

A possible biomass resource with benefits for climate and biodiversity

Authors: Ebba Magnusson, Rebecca Watkins
Department of Space, Earth and Environment, Chalmers University of Technology

ABSTRACT

Lake meadows have historically been utilized for its fodder resources, both through grazing and yearly harvest. As the agricultural system became industrialized around the 20th century, the importance of lake meadows as fodder resource however decreased. The ceased maintenance has caused a regrowth of sly, reed and even woody vegetation around many lakes.

This thesis investigates the possible benefits for climate and biodiversity of harvesting meadows along regrown lakes within the region of Västra Götaland, with lake Tydjesjön as a case study. The climate impact and the effects on flora and fauna is assessed for using different management techniques; mowing, grazing and through harvesting with biomass processing through composting, incineration, anaerobic digestion, and pyrolysis. The thesis also investigates the feasibility of managing overgrown lake meadows from a financial and technical perspective and barriers for individual landowners.

The methods used included a literature review, interviews, quantitative analyses, and a field trip. Climate impact was evaluated quantitatively by comparing net greenhouse gas emissions for different management techniques. Biodiversity impact was evaluated qualitatively with a literature review supporting own assessment of impacts on threatened species in regrown lakes. The feasibility was evaluated both quantitatively by calculating the profitability with and without the use of an external contractor, and qualitatively by interviews with landowners and individuals at the County Administrative Board of Västra Götaland and waste management companies.

The results indicate that management of lake meadows can contribute positively to climate change mitigation, especially if the vegetation is harvested and used for biogas production. For biodiversity, all investigated management options tend to be positive, but grazing has the highest benefits for a rich flora and fauna. There are, however, many challenges linked to increased management of lake meadows. There's a limited availability of cattle due to lean grazing and risk for parasites. The meadows are technically difficult to harvest and fundings via support schemes that can be applied includes risk taking for the applicant. In addition, the willingness to accept the harvested biomass for incineration and pyrolysis processes is low. For the lake meadows to be managed to a greater extent than today, it requires a large portion of personal engagement and interest from the landowner. For a larger transformation to happen, a higher profitability is needed, more suitable machines must be available to landowners, the support schemes need to be simplified and entail a lower risk, and the waste management production units need to be better fitted to use harvested lake meadow biomass as raw material.

Keywords: Lake meadows, Reed, Climate impact, Biodiversity, Lake maintenance, Lake restoration, Harvest, Renewable energy, Biogas, Biochar

TABLE OF CONTENTS

Table of figures and tables

1. INTRODUCTION

1.1. Background

The rapid changes in human activity in the last century have explicitly led to increased greenhouse gas emissions and as a result increased global warming. The global temperature has already seen rise 1.1º C since pre-industrial time, whereas the Paris agreement, adopted in 2015, set the goal to pursue to limit the global temperature increase to 1.5º C since pre-industrial time. The implications for changed human activity do not only impact climate, but also biodiversity on earth as these are interdependent of one and other. Wildlife population is seen to have dropped 69% since 1970. The alteration in human activity comes from changes in the use of energy and land but also from changes in lifestyle and consumption pattern. The vast impact from land changes primarily comes from a shift in land-use change altering the land into agricultural land, as a result of changed and increased food patterns globally. This land-use change is seen to be the biggest threat to nature and impacts both climate and biodiversity (Trisos et al., 2023; WWF & ZSL, 2022).

Land-use changes are not only seen by deforestation and increased cultivation, but also by decreased management of some areas, due to changes in agricultural practices. This type of land-use change can for example be seen on land where profitability is decreased and on land that is difficult to manage, like lake meadows. Biomass growing in connection with lakes has the possibility to act as protection zones, preventing soil erosion and run-off of fertilizers and pesticide from cultivated fields into the surrounding water compartments. Historically, the biomass within these areas has been harvested and used for animal winter feed, or animals have been allowed to graze the area. Today, lake meadows are often not managed leading to a gradual change towards a dominance of sly and reed, which has negative effects for the local biodiversity.

During 2021, the European Union implemented a tightened legislation that 40% of the energy use within the Union should come from renewable energy by 2030. An important part of that renewable energy is predicted to come from biomass (EU - Förnyelsebar Energi, n.d.). Simultaneously, recent suggested strategies in Sweden aims for the country to increase domestic production of biofuels from domestic biomass, at a scale of self-sufficiency, by 2045. The strategy also includes the aim of replacing fossil-based products by biobased products, with the help from increased biorefineries (Bioekonomiutredningen & Ek, n.d.).

With an increasing demand for biomass for energy production and biobased products to reduce global warming, alternative biomass resources must be investigated. It is therefore relevant to assess if harvesting of lake meadows could contribute to a new biomass resource, and simultaneously have positive impact on local biodiversity.

1.2. Aim

The aim of the thesis is to analyze the possibilities to harvest biomass from meadows along lakes, with lake Tydjesjön, Åmål as a case study. The thesis will examine possible uses of the harvested biomass and the benefits and drawbacks for biodiversity and climate. The thesis also aims to investigate the feasibility of harvesting lake meadow biomass in a larger scale; the possibilities and hinders based on economic aspects, the scalability, lack of infrastructure or technological challenges that must be addressed.

1.3. Limitations

Lake Tydjesjön is used as a case study for the thesis. The study, however, focuses on overgrown lakes in the whole region of Västra Götaland. Interviews have been performed with landowners and land-users around Tydjesjön, but the potential benefits for climate and biodiversity of harvesting lake meadows is more general and does not originate from this or any other specific lake. Furthermore, marine beaches and meadows along rivers are excluded from the study.

Climate impact is assessed mainly based on three species of plants: common reed, reed canary grass and cattail. Other plants, such as acute sedge and great mannagrass, may however be relevant in overgrown lakes and have other properties.

There is no established framework to analyze and evaluate the changes in biodiversity in a quantitative manner. The impact of different management techniques on flora and fauna is therefore evaluated qualitatively, focusing on red-listed or threatened species.

The feasibility study is focused on incentives for individual landowners to restore and maintain lake meadows. The feasibility for municipalities, or profitability for waste management businesses are not in focus in the thesis, and only covered briefly.

For further limitations and system boundaries, see Method.

1.4. Specification of issues under investigation

The research questions for the thesis are the following:

- What type of flora and fauna can be found in overgrown lakes, specifically in meadows along lakes in the region of Västra Götaland?
- How have lake meadows been maintained historically, and how are they managed today? What are the possible uses of the harvested biomass?
- What is the climate impact of using harvested biomass for different purposes?
- What are the local effects on biodiversity of different management techniques?
- Is it feasible to restore and maintain meadows continuously within a larger region/area and use the biomass for different purposes?
    - from an economical point of view (profitability, fundings, and scalability)?
    - based on barriers for individual landowners?
    - from a technical point of view?

2. METHOD

2.1. Theory

2.1.1. Literature review

A literature review was performed to investigate the historical maintenance of lake meadows, management techniques, waste management possibilities, flora and fauna in overgrown lakes and subsides available for restoration and maintenance.

Articles and information were retrieved mainly from searches made in Chalmers Library, Web of Science, Google Scholar, and Google. Search terms were used in both English and Swedish. Search terms used included [reed, harvest, overgrowth, lakes, emissions, carbon, grazing, waste management, biomass, restoration, pyrolysis, biochar, reed, incineration, biogas, anaerobic digestion, etc.].

As the thesis focuses on Sweden, articles studying systems and areas in Sweden were prioritized, studies concerning Nordic countries came second and studies applying northern Europe in third hand (for example as in the case of yield and typical vegetation which differs based on location). Articles studying marine beaches and tropical areas were disregarded.

Information regarding funding available for lake meadow restoration and maintenance were retrieved from Swedish EPA, the Swedish Board of Agriculture, and County Administrative Board of Västra Götaland.

2.1.2. Field trip and interviews

A field trip was made to the case-study area, Lake Tydjesjön, in the start-up-phase (January 2023) to get a general understanding of the causes and effects of regrowth in lakes. Niklas Wahlström, Climate strategist at Åmål Community, guided the visit, and was interviewed at the same time.

Fredrik Fredriksson, County Administrative Board of Västra Götaland, was interviewed twice (February and March), concerning the view from a regional perspective as well as the system, procedures and requirements which apply when a landowner or a municipality applies for financial support/funding. Gunnar Flygh, Peder Hedberg Fält, and Christer Ivarsson from the County Administrative Board were also interviewed concerning the same aspects.

Arne Linding, LVR Våtmarsrestaurering AB, was interviewed in February and March concerning equipment and techniques used for mowing and harvest, and concerning costs, time consumption and conditions during mowing and harvest.

Finally, several waste treatment companies were contacted for information regarding waste handling, and possibilities and barriers to use harvested biomass as a resource.

2.2. Determination of climate impact

Climate impact was calculated based on an LCA approach. The following section describes the methodical choices, inventory data and equations used to determine the climate impact of using harvested lake biomass for different purposes.

2.2.1. Scenarios and functional unit

The functional unit for determining the climate impact based on different management techniques was set to **1 ton dry mass (tDM) of lake meadow biomass**. Climate impact was calculated based on GWP100.

Five different scenarios to manage lake meadows manually (without grazing) were evaluated:

1. Mowing, Business as usual (BAU):
    - Cutting the harvested biomass and leaving the biomass on site without any gathering.
    - Based on interviews with County Administrative Board of Västra Götaland, landowners and companies working with harvesting, this is the most common method today for mechanical management of lake meadows.
2. Harvest and composting:
    - Cutting and collection of the harvested biomass, transport to composting facility.
    - This method is not used to a high extent today but would be possible to implement without any major technical changes.
3. Harvest and incineration:
    - Cutting and collection of the harvested biomass, transport to an external site for further treatment in a combined heat and power plant (CHP).
    - Incineration of harvested biomass could potentially be used since CHP facilities already exist, and since there is an increasing demand for biomass for energy production. Some challenges, however, exist for this option to be realized: combustion of harvested biomass from lake meadows creates a relatively high ash content which may cause problems in the process (Komulainen et al., 2008a). Biomass harvest will also be unevenly distributed throughout the year, and the amounts are low in comparison with other waste streams, which may create logistical challenges.
    - *Case 1: Electricity and district heating from CHP plants replacing electricity from natural gas, and district heating from mixed waste.*
    - *Case 2: Electricity and district heating from CHP plants replacing an average Swedish electricity mix, and district heating from mixed waste.*
4. Harvest and anaerobic digestion:
    - Cutting and collection of the harvested biomass, transport to an external biogas facility (assuming that anaerobic digestions and biogas upgrading is performed in the same plant).
    - Anaerobic digestion of harvested biomass could potentially be used since facilities already exist biogas production, and since there is an increasing demand for biomass for biofuels.
5. Harvest and pyrolysis:
    - Cutting and collection of the harvested biomass and transport to a pyrolysis plant.
    - *Case 1: Pyrolysis in a stand-alone process, a small facility with a process adopted for high biochar yields and without energy recovery.*
    - *Case 2: Pyrolysis in a large-scale integrated process, a plant with possibility to recover energy for district heating and with lower biochar yields.*

A scenario with mowing, collection of the harvested biomass and placing it on a pile in connection with the lake was excluded for two reasons: 1. It is assumed that the climate impact of placing harvested biomass on a pile has similar climate impact as composting (excluding transport). 2. The cost for management doubles in case of using an external contracting firm (Bäckström, 2023; Linding, 2023), and therefore seldomly occurs.

2.2.2. Vegetation and yields

The vegetation in overgrown lakes consists of high growing reeds and grasses, whereof common reed, reed canary grass and cattail were identified to be three of the most common ones based on literature. Characteristics and properties for these species are also available in literature to a higher extent than others. Other vegetation may occur in lake meadows and be of interest for harvesting, but these are assumed to have similar properties.

The yield level depends on species of lake meadow biomass, the surrounding temperature, and the circumstances in the lake. For common reed, the yield may for example range between 3 to extreme cases of more than 40 tDM/ha/yr (van der Sluis et al., 2013). In Sweden, the yield is normally in the lower range, and the average yield for lake meadow biomass was therefore assumed to be 5 tDM/ha/yr (Köbbing et al., 2013; Mola-Yudego et al., 2021).

2.2.3. Emissions from land

The carbon dioxide taken up by photosynthesis was calculated based on the average carbon content in common reed and reed canary grass. (Several sources were identified for these two species, and two studies with a share assessed as representative for the average carbon content was chosen for further calculations.) Carbon content in cattail was not found in literature and was therefore assumed to be equal to the average value of common reed and reed canary grass.

- Common reed: 42.3% DM (Hultberg et al., 2018a)
- Reed canary grass: 47.0%, DM (Heinsoo et al., 2011)
- Cattail: 45.3% DM (average of common reed and reed canary grass)
- Average carbon content, feedstock: 453 kgC/tDM

$$CO_2e_{photosyntesi}\ (\frac{kgCO_2e}{tDM}) = 453\,\frac{kgC}{tDM} \times \frac{44\ kgCO_2}{12\ kgC} \tag{1}$$

Decomposition of biomass mainly emits CO_2, N_2O and CH_4. When lake meadow biomass is cut in wetlands and decomposes on site, the N_2O emissions are generally very low. In wet conditions, up to 15% of the carbon from the biomass can be emitted as methane during decomposition (Günther et al., 2015). However, since the BAU scenario includes mowing and leaving the cut biomass distributed over the meadow in open air and with rich oxygen supply, and the fact that mowing is generally performed on land (not in the water or on wet land where buoyancy is low and can't carry the machines), it was assumed that the emissions of N_2O and CH_4 was negligible in this case and that all carbon emitted was in the form of CO_2.

No data was found regarding carbon retention to soil from natural decomposition in wetland. The CO_2 emissions from the cut biomass (mowing/BAU scenario) were therefore calculated based on the assumption that 90% of the carbon taken up through photosynthesis is emitted back to the atmosphere, while 10% remains in the soil. This is comparable with carbon retained in soil when applying a compost product as soil improver (2% to 16%) (Ermolaev, 2015).

$$CO_2e_{decomposition}(\frac{kgCO_2e}{tDM}) = CO_2e_{photosyntesi}\ (\frac{kgCO_2e}{tDM}) \times\ 0.9 \quad (2)$$

$$Avoided\ CO_2e_{decomposition}(\frac{kgCO_2e}{tDM}) = CO_2e_{photosyntesi}\ (\frac{kgCO_2e}{tDM}) \times\ 0.1 \quad (3)$$

For the scenarios including harvest of biomass, it was assumed that the cut and cleared meadows were not affected by the loss of biomass. Higher temperatures reaching the bare soil, and less biomass addition, may lead to increased carbon emissions from soil. However, a study comparing harvested peat land with control sites did not see any increase in GHG emissions due to harvest for temperatures comparable with Swedish conditions (15°C) (Liu et al., 2019) and it was therefore assumed that this had negligible effects on soil emissions.

2.2.4. Mowing/Cutting

Average fuel consumption used by machines for harvesting has been estimated based on interviews with Arne Linding, LVR Våtmarksrestaurering AB. Estimation was done on an average fuel consumption of 8.5 liters/hour, and an average harvesting speed of 1 ha on 4-6 hours, leading to a total fuel consumption of approximately 50 liters fuel per ha harvested.

Emissions from mowing was calculated based on using diesel MK3 as fuel in the harvesting machine, emitting 3.244 kg CO_2e/l fuel (Energimyndigheten, 2021).

$$CO_2e_{mowing}(\frac{kgCO_2e}{tDM}) = \frac{3.244\frac{kgCO_2e}{l} \times 50\frac{l}{ha}}{5\frac{tDM}{ha}} \quad (4)$$

2.2.5. Collection

The energy needed for collection of cut biomass (baling or collection into bags) is according to a study 99.2 MJ/tDM (Hetz & Sonesson, 1993). Diesel MK3 was assumed to be used as fuel also in this case, contributing to 0.0908 $kgCO_2e$/MJ (Energimyndigheten, 2021).

$$CO_2e_{collection}(\frac{kgCO_2e}{tDM}) = 99.2\,\frac{MJ}{tDM} \times\ 0.0908\,\frac{kgCO_2e}{MJ} \quad (5)$$

2.2.6. Transports

For transportation of harvested biomass to be economically feasible, the transportation range has in a previous study been identified to be between 90-120 km. Baled biomass can be transported longer distances than non-baled biomass (Komulainen et al., 2008a). In this thesis, a distance of 30 km was used for the calculations as a base case. Facilities for energy recovery (CHP) can be found in Skövde, Uddevalla, Göteborg, and Lidköping, within the region of Västra Götaland, making these quite well distributed over the whole region. Pyrolysis may in future be performed in Göteborg (Tagene), but smaller pyrolysis plants adopted for lake meadow biomass (which has been used as a scenario) could potentially be built and distributed over the region.

The GHG emissions from transportation of harvested biomass were based on an emission rate of 0.052 kgCO2e/tkm (Baumann & Tillmann, 2004).

Since the harvested biomass cannot be dried on site/at the lake, the biomass must be transported in wet condition. The moisture content of common reed at harvest is between 41-44% (Hultberg et al., 2018b). The moisture content in the dry weight is approximately 20% (Köbbing & Zerbe, 2013).

Based on these values, it was assumed that the wet mass (WM) of the harvested biomass was 1.2 tWM/tDM.

$$CO_2e_{transport}(\frac{kgCO_2e}{tDM}) = 30\ km \times\ 0.052 \frac{kgCO_2}{tWM \times km} \times\ 1.2\ \frac{tWM}{tDM} \tag{6}$$

2.2.7. Composting

Compost was assumed to be performed in a large-scale covered windrow compost at an external facility. The emissions were calculated based on kgCO_2e/kg C emitted, based on (Ermolaev, 2015):

- CO_2: 3.63 kg CO_2e/kg C emitted
- CH_4: 0.448 kg CO_2e/kg C emitted
- N_2O: 0.0334 kg CO_2e/kg C emitted

In windrow composting, the carbon emitted to the atmosphere is in average 48% (assuming that the carbon emitted only originates from carbon released as methane and carbon dioxide) (Ermolaev, 2015). 52% of the initial carbon in the feedstock was assumed to remain in the final compost product.

$$CO_2e_{compost}(\frac{kgCO_2e}{tDM}) = \frac{(3.63+0.448 \quad .0334)\ kgCO_2e}{kgC} \times \frac{(C_{feedstock} \times 0.48)\ kgC}{tDM} \tag{7}$$

Peat based products is commonly used as soil improvers. If a compost product (centrally produced) is used instead of a peat-based product, approximately 130 kg peat/ton (Boldrin et al., 2011) compost product is normally avoided in real-life use (Ermolaev, 2015). The carbon content in peat is approximately 40% (Agus et al., 2011), corresponding to 1467 kgCO_2e/t peat if all carbon stored in the peat is emitted as carbon dioxide when used as soil improver.

The mass of a compost product is approximately 50% of the initial feedstock (based on data for wheat straw) (Verma et al., 2014). It was assumed that the harvested biomass enters the composting process in wet condition, and the mass of the compost product was hence calculated based on 1.2 tWM/tDM.

$$Avoided\ CO_2e_{compost}\left(\frac{kgCO_2e}{tDM}\right) = 0.5 \frac{t\ compost\ produ}{tWM} \times\ 1.2 \frac{tWM}{tDM} \times\ 0.13 \frac{t\ peat}{t\ compost\ product} \times 1467\ \frac{kgCO2}{t\ peat} \tag{8}$$

When compost products are used as soil improver, 2-16% of the carbon remains in the soil after 100 years while the remaining share is emitted to the atmosphere (Ermolaev, 2015). Based on this, it was assumed that 90% of carbon in the compost product was emitted as carbon dioxide.

$$CO_2e_{compost\ product}\ (\frac{kgCO_2e}{tDM}) = 0.9\ \times \frac{(C_{feedstock} \times 0.52)\ kgC}{tDM} \times \frac{44\ kg\ CO_2}{12\ kg\ C} \tag{9}$$

2.2.8. Incineration

Incineration was calculated based on that the harvested biomass was treated in a combined heat and power plant (CHP) without industrial drying as a pre-treatment. It was assumed that no mass losses occurred between harvest and incineration, hence 100% of the harvested biomass could be utilized in the process. Furthermore, it was assumed that all carbon taken up by the plants (100%) was emitted back to the atmosphere as CO_2 during the combustion process.

The higher heating value (HHV) for the harvested biomass was used for calculating energy balances in incineration (Komulainen et al., 2008b).

- Common reed: 18.6 GJ/tDM
- Reed canary grass: 17.2 GJ/tDM
- Cattail: 17.7 GJ/tDM
- $HHV_{average}$ = 17.8 GJ/tDM

The efficiency is usually around 90% in a CHP. The electricity vs. heat output was assumed to be 32% and 79%, where the latter includes 21% of heat generated from flue gas condensation, corresponding to the energy output in Sobacken, Borås Energi och Miljö (Borås Energi och Miljö, n.d.).

The electricity produced in a CHP is provided into the Swedish electricity grid. The avoided CO_2 emissions for electricity was calculated based on CO_2e using the same share of electricity from other sources:

- Case 1: comparison with electricity on the margin, natural gas: 51.3 $kgCO_2e/GJ$ (Joint Research Center, n.d.).
- Case 2: comparison with average Swedish electricity mix: 13.1 $kgCO_2e/GJ$ (Energimyndigheten, 2021).

The heat produced in a CHP is distributed to households as district heating. The avoided CO_2 emissions for using harvested biomass as an energy source for district heating, was calculated based on direct emissions generated from waste treatment by Stockholm Exergi; 46 gCO_2e/kWh (12.8 kg CO_2e/GJ) (Stockholm Exergi, 2023).

$$CO_2e_{incineration}\left(\frac{kgCO_2e}{tDM}\right) = CO_2e_{photosynthesis}\left(\frac{kgCO_2e}{tDM}\right) \tag{10}$$

$$Avoided\ CO_2e_{incineration,case\ 1}\left(\frac{kgCO_2e}{tD}\right) = 17.8\frac{GJ}{tDM} \times \left(0.32 \times 51.3\frac{kgCO_2}{GJ} + 0.79 \times 12.8\frac{kgCO_2}{GJ}\right) \tag{11}$$

$$Avoided\ CO_2e_{incineration,case\ 2}\left(\frac{kgCO_2e}{tDM}\right) = 17.8\frac{GJ}{tDM} \times \left(0.32 \times 13.1\frac{kgCO_2}{GJ} + 0.79 \times 12.8\frac{kgCO_2}{GJ}\right) \tag{12}$$

2.2.9. Anaerobic digestion and biogas upgrading

Before the anaerobic digestion takes place, the harvested biomass must be chopped into smaller fractions. This process requires approximately 142 MJ/ha, corresponding to 0.028 GJ/tDM (Hetz & Sonesson, 1993). Mass losses will likely occur during this stage, but data has not been found regarding the share of these losses and were therefore excluded from the calculations.

During the anaerobic digestion process, 0.11 GJ heat and 0.066 GJ electricity is required for the process (Oleszek & Matyka, 2020). An average electricity mix was assumed to be used for the energy input to the process, emitting 13.1 kgCO2e/GJ (Energimyndigheten, 2021).

$$CO_2e_{pretreatment\ biogas}\left(\frac{kgCO_2e}{tDM}\right) = 13.1\frac{kgCO_2}{GJ} \times \left(0.028\frac{GJ}{tDM} + 0.11\frac{GJ}{tDM} + 0.066\frac{GJ}{tDM}\right) \tag{13}$$

The products generated from anaerobic digestion are biogas, solid digestate and liquid digestate. For wheat straw, 50% of the initial carbon is transferred into the biogas during the anaerobic digestion, while the remaining share ends up in the digestate products (Gao et al., 2020). It was assumed that the same carbon flows occur for lake meadow biomass. The digestate products can be used for soil improvement/fertilizers. The solid and liquid digestate have different properties, where the solid fraction is more carbon rich, and the liquid fraction contains minerals important for plant growth (Slepetiene et al., 2023). Since both fractions can be used as fertilizers (Czekała et al., 2022), avoided CO_2 emissions were calculated based on the carbon which can potentially be transferred back to the soil through both liquid and solid digestates. As for compost products, it was assumed 10% of the carbon in the digestate remains in the soil after 100 years.

$$CO_2e_{digastate}\left(\frac{kgCO_2e}{tDM}\right) = C_{feedstock}\left(\frac{kgC}{tDM}\right) \times 0.5 \times \frac{44\ kgCO_2}{12\ kgC} \times 0.9 \quad (14)$$

$$Avoided\ CO_2e_{digastate}\left(\frac{kgCO_2e}{tDM}\right) = C_{feedstock}\left(\frac{kgC}{tDM}\right) \times 0.5 \times \frac{44\ kgCO_2}{12\ kgC} \times 0.1 \quad (15)$$

Heat is generated during anaerobic digestion, which may be recovered and used for district heating or for processes on site. The avoided emissions from energy recovery from excess heat were however excluded from the calculations since the utilization of this energy may differ between different plants.

The production of biogas and biomethane may lead to methane slips/leakages from the process. According to EU RED, agricultural residues with density $< 0.2\ t/m^3$, transported between 1-500 km, typically emits 0.9 gCO_2e/MJ during processing (EC, n.d.). For simplicity, all methane slips are presented as leakages from anaerobic digestion in the flow charts. The energy content in biomethane is 36 MJ/m^3 (IEA, n.d.).

$$CO_2e_{slips}\left(\frac{kgCO_2e}{tDM}\right) = 246\frac{m^3CH_4}{tDM} \times 36\frac{MJ}{m^3CH_4} \times 0.0009\frac{kgCO_2e}{MJ} \quad (16)$$

After anaerobic digestion, the biogas is upgraded to biomethane. The average biogas potential for the three vegetation types was used for calculations of biomethane yield and biogas energy content. The tVS/tDM for lake meadow biomass was estimated to be 90%.

- Common reed: 302 $LCH_4/kgVS$ (Lizasoain et al., 2016)
- Reed canary grass: 263 $LCH_4/kgVS$ (Dubrovskis et al., n.d.)
- Cattail: 255 $LCH_4/kgVS$ (Zhang et al., 2020)
- Biogas $potential_{average}$: 273 $LCH_4/kgVS$ = 246 m^3CH_4/tDM

The upgrading process has an electricity consumption of 0.22 kWh/Nm^3 biogas according to (Bright Renewables, n.d.) and it was assumed that 1 Nm^3 = 1 m^3CH4. The emissions from electricity needed for purification was based on the use of an average electricity mix (13.1 $kgCO_2e/GJ$) (Energimyndigheten, 2021).

$$CO_2e_{upgrading}\left(\frac{kgCO_2e}{tDM}\right) = 13.1\frac{kgCO_2}{GJ} \times 0.22\frac{kWh}{Nm^3} \times 3.6\frac{MJ}{kWh} \times 0.001\frac{GJ}{MJ} \times 246\frac{m^3CH_4}{tDM} \quad (17)$$

The upgrading process of the biogas generates 50-70% CH_4 and 30-45% is CO_2 of the initial 100% biogas input (GIZ, n.d.). An average value was assumed for the harvested biomass, i.e., that 60% of the biogas output is biomethane, while the remaining share is carbon dioxide. It was assumed that this ratio referred to the mass of the biogas. The molar mass of methane is 16.04 g/mol, and the molar mass for carbon dioxide is 44.01 g/mol, and when calculating the carbon flows based on the different masses of the two substances, 73% of the carbon is transferred into the biomethane, while 27% is separated out in the form of biogenic carbon dioxide. Due to methane slips in the anaerobic digestions, less carbon enters the upgrading process compared to the initial feedstock. According to IPCC, GWP100 for methane is 28.

$$C_{slips}(\frac{kgCO_2e}{tDM}) = \frac{CO_2e_{CH4,slips}\,(\frac{kgCO_2}{tDM})}{28\,(\frac{kgCH_4}{kgCO_2})} \times \frac{12\ kgC}{16\ kgCH_4} \tag{18}$$

The biogenic carbon dioxide will be emitted to the atmosphere when it is used, but the same amount of GHG will also be avoided when fossil CO_2 can be replaced.

$$CO_2e_{\ bioCO2}(\frac{kgCO_2e}{tDM}) = \left(C_{feedstock} - C_{slips}\ - C_{digastate}\right)\frac{kgC}{tDM} \times \frac{44\ kgCO_2}{12\ kgC} \times 0.27 \tag{19}$$

$$Avoided\ CO_2e_{\,bioC}\quad(\frac{kgCO_2e}{tDM}) = CO_2e_{\ bioC\quad,\ biogas} \tag{20}$$

Biomethane can be used as fuel in cars, and the carbon is emitted to the atmosphere when combusted. It was assumed that all carbon was emitted in the form of CO_2.

$$CO_2e_{\ biomethan}\ (\frac{kgCO_2e}{tDM}) = \left(C_{feedstock} - C_{slips} - C_{digastate}\right)\frac{kgC}{tDM} \times \frac{44\ kgCO_2}{12\ kgC} \times 0.73 \tag{21}$$

The energy content in biomethane is 36 MJ/m^3 (IEA, n.d.). The avoided emissions from using biomethane was compared to the emissions from the average fleet of cars in Sweden using the same amount of energy for fuel. 34.6% of the cars in Sweden are diesel-driven and 51.8% is petrol cars (Trafikanalys, 2022). The emissions from diesel cars were based on MK1 diesel; 73 gCO2e/MJ and emissions from petrol cars were based on MK1 gasoline; 88.5 gCO2e/MJ (Energimyndigheten, 2021).

$$Avoided\ CO_2e_{\,biomethan}\ (\frac{kgCO_2e}{tDM}) = 246\frac{m^3}{tDM} \times 36\frac{MJ}{m^3}\ \times\ (0.346\ \times 0.073\frac{kgCO_2e}{MJ} + 0.518\ \times 0.0885\frac{kgCO_2e}{MJ}) \tag{22}$$

2.2.10. Pyrolysis

Before pyrolysis, the harvested biomass must be dried and chopped into smaller fractions. Mass losses will likely occur during these stages, but the shares have not been found and are therefore disregarded. The chopping is assumed to require approximately 142 MJ/ha (as for biogas production), corresponding to 0.028 GJ/tDM. The drying was assumed to require 3.5 MJ/kg water evaporated (Havlík & Dlouhý, 2020). The average moisture content of the three plants is 15%, DM, and 42%, WM, leading to 0.27 ton water that needs to be evaporated per ton dry mass. An average electricity mix was assumed to be used for the energy input to these processes, emitting 13.1 kgCO_2e/GJ (Energimyndigheten, 2021).

$$CO_2e_{pretreatment\ pyrolysis}\,(\frac{kgCO_2e}{tDM}) = 13.1\frac{kgCO_2}{GJ} \times (0.028\frac{GJ}{tDM} + 0.27\frac{t\ water}{tDM} \times 3.5\frac{GJ}{t\ water}) \tag{23}$$

Two processes for pyrolysis can be used:

- Case 1: A stand-alone process in a small pyrolysis plant, operating at lower temperatures to get a maximum yield of biochar. The remaining energy is consumed in the process and excess energy is lost as heat.
- Case 2: An integrated process in a large-scale plant, usually using a temperature of approximately 500°C. Around 1/3 of the energy produced is in this case used for district heating, 1/3 for the biochar, and 1/3 of the energy is used to run the process (Göteborg Energi, n.d.).

Both cases were calculated for comparison and are presented in the results, but the integrated process will likely not be relevant for harvested biomass since large scale plants mainly is adopted for forest residues.

The char yield and carbon content in char was calculated based equations found in literature (Abhijeet et al., 2019). Temperature (T) was set to 350°C for case 1, and 500°C for case 2.

$$Biochar\ yield,\ Y_{biochar}\left(\frac{t\ biochar}{tDM}\right) = 0.106 + 2.43 \times\ EXP(-0.66\ \times\ T\ \times\ 10^{-2}) \tag{24}$$

$$Carbon\ content\ in\ biochar, C_{bioch}\ \left(\frac{tC}{t\ biochar}\right) = 0.93 - 0.92 \times\ EXP(-0.42\ \times\ T\ \times\ 10^{-2}) \tag{25}$$

The avoided emissions from storing carbon in biochar were based on the carbon content in the biochar. The CO_2 emissions from the pyrolysis were calculated based on the difference between carbon in feedstock, and the carbon in the biochar.

$$Avoided\ CO_2e_{biocha}\ (\frac{kgCO_2e}{tDM}) =\ C_{biochar}\ (\frac{kgC}{t\ bioch}) \times\ Y_{biochar}(\frac{t\ bioch}{tDM}) \times\ \frac{44\ kgCO_2}{12\ kgC} \tag{26}$$

For case 2, 30% of the energy produced was assumed to be used for district heating. The avoided CO_2 emissions for using harvested biomass as an energy source for district heating, was calculated based on that it would replace regular district heating emitting 46 gCO_2e/kWh (12.8 kg CO_2e/GJ) (Stockholm Exergi, 2023).

$$Avoided\ CO_2e_{pyrolysis,case2}\ (\frac{kgCO_2e}{tDM}) =\ 17.8\frac{GJ}{tDM}\ \times\ 0.3\ \times\ 12.8\ \frac{kgCO_2}{GJ} \tag{27}$$

The emissions from the pyrolysis were calculated based on that all carbon not stored in the biochar was emitted to the atmosphere as CO_2.

$$CO_2e_{pyrolysis}\ (\frac{kgCO_2e}{tDM}) =\ (C_{feedstock} - C_{biocha}\ )\frac{kgC}{tDM}\ \times\ \frac{44\ kgCO_2}{12\ kgC} \tag{28}$$

2.2.11. Flowcharts with climate impact and carbon flows

The results were summarized in flowcharts, one per management method, with emissions in CO_2e (rounded to whole numbers), and carbon flows (with two valid numbers). The biogenic carbon dioxide was presented in color green, and the fossil emissions were presented in color black.

For pyrolysis, only case 1 (the stand-alone process) was presented as a flowchart (case 2 was however included in table of results).

2.3. Assessment of biodiversity

2.3.1. Scenarios

The impact on biodiversity based on different management techniques were evaluated qualitatively, partly based on information retrieved from literature and partly by assessing the impact on biodiversity in overgrown lakes within the region of Västra Götaland. The following scenarios were assessed:

1. Mowing (BAU):
    - Cutting the lake meadow biomass and leaving it on site without any gathering.
    - Based on interviews with the County Administrative Board of Västra Götaland, landowners and companies working with biomass harvesting, this is the most common method today for mechanical management of lake meadows.
2. Harvest:
    - Mowing, collection of lake meadow biomass and removal from the site.
    - This method is not used to a high extent today.
3. Grazing:
    - Using cattle for restoration and maintenance of lake meadows.
    - The most common management method used.

No other management techniques for restoration and management of lake meadows were identified, hence no scenarios were knowingly excluded from the assessment.

2.3.2. Impact assessment based on literature review and interviews

A literature study was performed to identify earlier findings regarding connections between management techniques in overgrown lakes and local biodiversity. Focus was put on scientific literature analysing overgrown lakes in the Nordic and the Baltic countries. Lake meadows in marine environments were not assessed. The findings were presented as part of the Theory.

A visit at the lake Tydjesjön was performed in January (2023-01-31) to understand the circumstances occurring in overgrown lakes. An interview was performed in connection with the visit with Niklas Wahlström, Climate and Environmental strategist at Åmåls Community.

The findings from the literature study were summarized to assess the impact on biodiversity based on different management practices in general.

2.3.3. Impact assessment based on information about fauna and flora in overgrown lakes in VGR

The impact on biodiversity in overgrown lakes within the region of Västra Götaland were evaluated based on typical and characteristic flora and fauna which can be found in lakes in the region. Inventorying species in a specific area and analyzing risks for protected and red-listed species (species threatened by extinction, evaluated by their current situation) can help prioritize nature conservation programs and evaluating suitable management practices (Artdatabanken - Rödlistning, n.d.).

The procedure to identify relevant species was roughly based on the guidance provided by the Swedish Environmental Protection Agency for how environmental assessments shall be performed when evaluating the impact on biodiversity in connection with plans and programs (Naturvårdsverket, n.d.-a).

In step 1, the guidelines for the Swedish nature types in Appendix 1 of the Habitats Directive, Swedish Environmental Agency, was assessed to determine the types of lakes which occur in the region of Västra Götaland, and the types of lakes which poses a risk for regrowth within the area. The typical and characteristic flora and fauna in these lakes, and which are under threat, were identified according to chapter 6 in Miljöbalken (Naturvårdsverket, n.d.-a):

- animals and plants in Artskyddskyddsförordningen (2007:845) (Sveriges Riksdag, n.d.), appendix 1 marked with S, N or n.
    - S: Naturally occurring in Sweden (excluding temporarily populations).
    - N: Species requiring protection according to the Habitats directive.
    - n: Species requiring protection according to Swedish assessments, but not included in the Habitats directive.
- animals and plants in Artskyddsförordningen (2007:845), Appendix 2, which assessed as vulnerable or threatened in Sweden specifically.
- naturally occurring birds in Sweden (frequently occurring in the country for nesting and resting, excluding temporarily occurring birds).
- animals and plants classified as vulnerable (VU), near threatened (NT) and endangered (EN) according to IUCN red list, assessed through Artportalen.se.

In step 2, a direct search in Artfakta.se was performed to identify any further threatened species, including insects (not included in search 1), in lake meadows (SLU, n.d.). The following filtering of search results were used:

- Arter:	Taxonkategori: Art
- Naturvård:	Rödlistekategori: CR, EN, VU, NT
- Geografi:	Län: Västra Götaland
- Ekologi:	Landskapstyp: Våtmark (V), Sötvatten (L) Biotop: Öppna strandbiotoper, Sötvattenstrand + Alternativ: Visa bara arter där biotopen är viktig
- Påverkan:	Negativ: Ökad näringsbelastning, Igenväxning, Upphörd hävd av öppen mark, Vattenreglering

The species identified as being under threat from the two searches (step 1 and step 2) were assessed individually to identify connections with regrowth in lake meadows and impact based on different lake meadow management techniques. Information regarding each species were retrieved from artfakta.se and were summarized shortly in case of connection with regrowth.

2.3.4. Flowchart with synthesized impact on biodiversity

The findings were consolidated into a flowchart, displaying the consequences each scenario will lead to in the lake meadows. To visualize that some management practises allow multiple choices (for example clear cutting vs. creating a mosaic pattern in the lake meadows), striped lines were used for this purpose.

Relation between each landscape consequence and its effect for flora and fauna, were furthermore included in the flowchart, both with connection lines and with colour coding. Since the actual flora and fauna differs from location to location, an overall assessment of the effect on plants vs animals was considered in this case, not impact based on individual species. The colour coding used was based on the impact on flora and fauna:

- Diverse flora (beneficial for threatened plants)
- Diverse fauna (beneficial for birds and red-listed animals)

- Monocultural vegetation (disadvantage for red-listed flora)
- Fauna disturbance (decrease in birds and threatened animals)

The colour coding used was based on impact both on flora and fauna:

- Green = only positive effects
- Yellow = more positive than negative effects
- Orange = equally positive and negative effects
- Dark orange = more negative than positive effects
- Red = only negative effects

2.4. Feasibility

2.4.1. Scenarios

The feasibility of different management techniques was evaluated based on costs and incomes from potential fundings and calculated in SEK/ha.
Six different scenarios to manage lake meadows were evaluated:

1. Mowing (BAU)
    - Cutting the harvested biomass once per year and leaving the biomass on site without any gathering.
2. Harvest and composting
    - Cutting and collection of the harvested biomass, transport to a composting facility.
3. Harvest and incineration
    - Cutting and collection of the biomass, transport to an external site for further treatment in a combined heat and power plant (CHP).
4. Harvest and anaerobic digestion
    - Cutting and collection of the biomass, transport to an external biogas facility (assuming that anaerobic digestions and biogas upgrading is performed in the same plant).
5. Harvest and pyrolysis
    - Cutting and collection of the biomass, transport to a pyrolysis plant.
6. Grazing
    - Cutting and collection of the biomass, one-time action, further grazed by cattle.

Each one of the scenarios were evaluated based on two cases:
1. Using a contractor for cutting and collection of lake meadow biomass. Landowner manages (pays for) transport to treatment facility.
2. Landowner manages and pays for cutting, collection of lake meadow biomass as well as transport to treatment facility. This option may occur, but seldom does, due to the difficulties of managing the wet lake meadows without the use of specially designed machines, which are rarely found at the common landowner.

2.4.2. Scalability

Approximately 4700 lakes can be found in the region of Västra Götaland, whereof four are classified as large (Länsstyrelsen Västra Götalands Län, 2021). The area of the inland water in the region, excluding the four large lakes, is 1449 km^2 (year 2023) and with a shoreline of 18557 km (year 2019) (SCB, n.d.-a). Based on estimation from Fredrik Fredriksson, the County Administrative Board of Västra Götaland, the lakes in the region (including Göta Älv, but excluding Vänern and Vättern) make up 8400 km of the shoreline, while the remaining distance is assumed to be rivers and watercourses. Around 60% of the shorelines have agricultural land located within 100 meters (approximately 5200 km).

The scalability was calculated based on 5200 km shoreline, since it was assumed that these lakes have a higher risk for regrowth compared to the average lake in the region. Based on the lake's proximity to farmland, they were furthermore assumed to be owned by private landowners who maintain or use other land in connection with the lake to a higher extent, and therefore may be interested in maintaining the lake meadows. It was also assumed that these lakes are more accessible with trucks and equipment.

2000 ha of the inland lake meadows in the region is today maintained to some extent and monitored by the County Administrative Board as a part of the Swedish environmental targets (focus on birds). To get a rough estimate of the scalability of lake meadow harvest in the region, a potential area was calculated based on different lake meadow widths, 10 respectively 100 meters, and different shares of lakes exposed to regrowth, 10 and 50%.

$$Potential\ area\ to\ harvest\ (ha) = shoreline\ (km)\ \times\ lake\ meadow\ width\ (km) \times\ regrown\ lakes\ (\%) \times\ 100 \frac{ha}{km^2} \quad (29)$$

2.4.3. Calculation of costs and profit

Costs and income were calculated based on the same scenarios used for determination of climate impact, but also for using the land for grazing.

The costs for harvesting of biomass from regrown meadows differs based on location, type of vegetation, transport distance, etc., and hence the calculation was performed to get a general picture of the possible profitability of each scenario. Individual landowners were in focus for the cost estimations, and the costs for waste management were therefore excluded from the calculations.

2.4.3.1. Costs

<u>Contracting</u>

Calculations for contractors cutting and collecting the lake meadow biomass have been done based on interview with LVR Våtmarsrestaurering AB. The cost has been estimated to be 2000 SEK/hour, with 4-6 hours needed/ha (Linding, 2023), and the cost has in the calculations therefore been set to the average value, 10 000 SEK/ha. The cost of collecting the cut biomass has, based on the same interview, said to be same as for cutting (Linding, 2023). Therefore, the cost for collecting lake meadow biomass has been set to same as for cutting, 10 000 SEK/ha.

<u>Cutting</u>

The fuel consumption needed to cut reed is according to interview 50 l/ha using a regular tractor (Linding, 2023). Diesel fuel cost was set to 24.5 SEK/l according to average sales litre price during 2022 (*Drivkraft Sverige*, n.d.).

$$Fuel\ cost\ cutting\ (\frac{SEK}{ha}) = 50 \frac{l}{ha}\ \times\ 24.5 \frac{SEK}{l} \quad (30)$$

<u>Collection of lake meadow biomass</u>

From Komulainen et. al's study the collection of biomass has a cost of 41.6 EUR/ha. This cost includes costs linked to machines acquisition price, hours of use per year, write off period and machine labour. This cost also includes human labour (Komulainen et al., 2008a). This price was converted to SEK by the conversion rate 2023-04-03, being 11.29 SEK.

Fuel consumption for collection of lake meadow biomass is 4.66 l/ha (Shinners & Friede, 2018; Suardi et al., 2020), and diesel fuel cost was set to 24.5 SEK/l according to average sales litre price during 2022 (*Drivkraft Sverige*, n.d.).

$$Cost\ collection\ of\ reed\ \left(\frac{SEK}{ha}\right) = \left(41.6 \frac{EUR}{ha}\ \times\ 11.29 \frac{SEK}{EUR}\right) + \left(4.66 \frac{l}{ha} \times\ 24.6 \frac{SEK}{l}\right) \quad (31)$$

Transportation

The transportation distance was set to 30 km. In this report, it is assumed that the transportation to waste management facility is done in the countryside, and paid for, by the landowners themselves. Therefore, the fuel consumption in calculations, 0.076 l/km, were based on a light truck (Transportsektorn, n.d.). Diesel fuel cost was set to 24.5 SEK/l according to average sales litre price during 2022 (*Drivkraft Sverige*, n.d.). From Komulainen et. al's study the transportation of reed has a cost of 8.82 EUR/ha. This cost includes costs linked to machines acquisition price, hours of use per year, write off period and machine labour. This cost also includes human labour (Komulainen et al., 2008a).

$$Cost\ transport\ of\ reed\ \left(\frac{SEK}{ha}\right) = \left(30km\ \times\ 0.076\frac{l}{km}\ \times\ 24.5\frac{SEK}{l}\right) + (8.82\frac{EUR}{ha}\ \times\ 11.29) \quad (32)$$

Cost parameters

Contracting is assumed to be an annual cost for all end-products, except for grazing. In this case the contracting for restauration is only done once, thereafter the cattle are grazing and maintaining the open land. The same applies to when landowners themselves manage the cutting.

Costs for chopping the biomass prior to further anaerobic or pyrolysis processing are excluded in the calculations and assumed to be performed at the waste treatment plant, hence not a direct cost for the landowner.

2.4.3.2. *Incomes and operational costs*

Grazing

For this report the assumption has been made that landowners lease their land to animal owners, who can have them grazing on their land. Hence, any costs linked to animal management is not included. Nor are the fundings included in the landowners' costs, as these will be paid to the managing animal owner. The animal owners leasing the land will pay a leasing fee to the landowner of 500 SEK/ha (Bäckström, 2023). This fee is symbolically for the feed that the animals can graze on their land.

Prior to grazing the lake meadow, a cutting and clearing of the biomass will be needed. This cost is denoted the landowner.

Composting

Operational costs for compost processing with windrow management has been calculated from 11.30 EUR/tDM (Hansson & Fredriksson, 2004). This price was converted to SEK by the conversion rate 2023-04-03, being 11.29 SEK. Yield was assumed to be 5 tDM/ha/yr, based on previous explanation. Further, the selling price of compost soil was calculated from 40 USD/m^3 (Rynk et al., 2022). This price was converted to SEK by the conversion rate 2023-04-03, being 10.32 SEK. Compost soil density of 250 kg/m^3 was used (Rynk et al., 2022). Compost product yield in a windrow process was set to 50% of ingoing material (Gao et al., 2020).

$$Operational\ cost\ Composting =\ 11.30\frac{EUR}{tDM}\ \times\ 11.29\frac{SEK}{EUR} \times 5\frac{tDM}{ha \times yr} \quad (33)$$

$$Selling\ price\ compost\ soil = 40\frac{USD}{m^3}\ \times\ 10.32\frac{SEK}{USD}\ \times 4\frac{m^3}{tDM} \times 5\frac{tDM}{ha \times yr}\ \times 0.5 \quad (34)$$

Incineration

Operational costs for incineration process in a CHP plant was calculated from 4.5 USD/MWh (Croon, 2013). This price was converted to SEK by the conversion rate 2023-04-03, being 10.32 SEK. Energy content of biomass was set to 17.8 GJ/tDM (Komulainen et al., 2008a). Yield was assumed to be 5 tDM/ha/yr, based on previous explanation.

Further, the selling of end products from incineration was divided between district heating and electricity. The selling price for DH was calculated from 339 SEK/MWh (*Göteborgs Energi*, n.d.), based on the energy content of biomass, 17.8 GJ/tDM (Komulainen et al., 2008a), and a share of 79% used for DH.

The selling price for electricity was calculated from the average selling price in Sweden during 2022, 1.45 SEK/kWh (*Energimyndigheten*, n.d.), based on the energy content of biomass, 17.8 GJ/tDM (Komulainen et al., 2008a), and a share of 32% used for electricity.

$$Operational\ cost = 4.5\frac{USD}{MWh} \times 10.32\frac{SEK}{USD} \times 17.8\frac{GJ}{tDM} \times \frac{1}{3.6}\frac{MWh}{GJ} \times 5\frac{tDM}{ha \times yr} \tag{35}$$

$$Selling\ price\ DH = 17.8\frac{GJ}{tDM} \times \frac{1}{3.6}\frac{MWh}{GJ} \times 339\frac{SEK}{MWh} \times 5\frac{tDM}{ha \times yr} \times 0.79 \tag{36}$$

$$Selling\ price\ electricity = 17.8\frac{GJ}{tDM} \times 277.8\frac{kWh}{GJ} \times 1.45\frac{SEK}{kWh} \times 5\frac{tDM}{ha \times yr} \times 0.32 \tag{37}$$

Anaerobic process

Operational cost for anaerobic process was calculated from 0.03 EUR/kWh (Sgroi et al., 2015) and on the energy content of biomass, 17.8 GJ/tDM (Komulainen et al., 2008a). The price was converted to SEK by the conversion rate 2023-04-03, being 11.29 SEK.

Further, the selling price of biofuel was calculated from the biogas potential of 246 m^3CH_4/tDM based on previous estimations. The methane content in biofuel used was 97% (Renewable Energy Agency, 2018), energy content in methane 9.9 kWh/m^3 (Norrman et al., 2005) and energy value in bioguel 13 kWh/kg (*Energigas Sverige*, n.d.). The selling price of 32 SEK/kg (*St1 Biogas*, n.d.) was used for the calculations, and the yield from biomass was assumed to be 5 tDM/ha/yr, based on previous explanation.

$$Operational\ cost = 0.03\frac{EUR}{MJ} \times 11.29\frac{SEK}{EUR} \times 1\,000\frac{MJ}{GJ} \times 4.98\frac{GJ}{tDM} \times 5\frac{tDM}{ha \times yr} \tag{38}$$

$$Selling\ price\ biofuel = \frac{\left(246\frac{m3\ CH4}{tDM} \times 97\% \times 9.9\frac{kWh}{m3}\right)}{13\frac{kWh}{kg}} \times 32\frac{SEK}{kg} \times 5\frac{tDM}{ha \times yr} \tag{39}$$

Pyrolysis process

Operational cost for the pyrolysis process was calculated from 173 USD/tDM (Yahya et al., 2021). Further, the selling price of biochar was calculated from 920 EUR/ton (Haeldermans et al., 2020). These prices were converted to SEK by the conversion rate 2023-04-03, being 10.32 and 11.29 SEK respectively. Yield was assumed to be 5 tDM/ha/yr, based on previous explanation and yield in biochar production was set to 35% (Abhijeet et al., n.d.).

$$Operational\ cost = 173\frac{USD}{tDM} \times 10.32\frac{SEK}{EUR} \times 5\frac{tDM}{ha \times yr} \tag{40}$$

$$Selling\ price\ biochar = 920\frac{EUR}{ton} \times 11.29\frac{SEK}{EUR} \times 5\frac{tDM}{ha} \times 0.35 \tag{41}$$

2.4.3.3. *Fundings*

Funding for restoration

Funding for restoration is 3 600 SEK/ha based on information through interviews (Bäckström, 2023; Flygh, 2023).

Funding for continued management

The amount of funding for continued management after the restoration period for general value was set to 3 900 SEK/ha (Bäckström, 2023; Flygh, 2023). However, if the land is considered having particular value, the funding increases to 6 000 SEK/ha (Bäckström, 2023; Flygh, 2023).

2.4.4. Financial and societal barriers

The financial and societal barriers were investigated through performing interviews with landowners and the County Administrative Board of Västra Götaland. The focus was mainly on financial aspects and barriers for applying for financial fundings for lake meadow maintenance, but societal barriers and incentives for maintaining lake meadows were also included as a topic for discussions. The interview group consisted of the following persons:

- Two landowners, partly leasing their land to a tenant and having no own maintenance of lake meadows.
- Two landowners, also being tenants, actively maintain their own and others land, and partly maintain the lake meadows.
- Three persons at the County Administrative Board of Västra Götaland, having expertise regarding the procedure for applying for financial support (Fredrik Fredriksson, Christer Ivarsson and Gunnar Flygh).

2.4.5. Technical feasibility

The technical feasibility was assessed throughout the study. The main method of retrieving information has been from the literature review to gain insight to the technologies used at waste treatment plants, as well as their current use of lake meadow biomass as raw material in their processes.

Articles and information were retrieved mainly from searches made in Chalmers Library, Web of Science, Google Scholar, and Google. Search terms were used in both English and Swedish. Search terms used included [incineration, CHP, anaerobic process, pyrolysis process, biochar, biogas, waste management, biomass, reed, anaerobic digestion, etc.].

The scientific literature review has also been complemented by interviews with the industry, several times during March and April for input regarding the waste management processes, techniques and common practice today. The interview also gave information regarding waste handling, and possibilities and barriers to use the harvested biomass as a resource.
Furter interviews, during February and March, have been performed with Arne Linding, LVR Våtmarsrestaurering AB, for input regarding equipment and techniques used for mowing and harvest, and to get a general picture of possibilities and challenges during mowing and harvest.
Landowners as well as the County Administrative Board of Västra Götaland was also interviewed adding perspective to the possibilities of mowing and harvesting.

2.4.6. Cost tables and synthesized financial results

Results of the costs and profits are presented in two tables, showing the balance of costs and profits from mowing and harvesting biomass. The social, financial, and technical feasibility are qualitatively discussed.

3. THEORY

3.1. Historical importance of lake meadows

Historically in the agricultural society, and even as far back in time as the iron age, meadows have had an important role for humans. Primarily the meadows were grazed, but during the beginning of the iron age, colder climate led to year-round grazing being impossible, thus new management practices were introduced. As access to iron increased, so did the possibilities to mow the meadows with scythes. Meadows were the main source for animal feed, directly during spring and summer months, but also to a stable winter feed. Lake meadows served the same function, however if the meadow was too wet, primarily grazing was used for immediate consumption by the grazing animals. During history, most meadows were harvested or grazed for animal feed. The transformation of biomass, by grazing animals, made the vegetation a key to stable food supply as well as a source to manure. This manure was used for agriculture of other eatable crops. The importance meadows had in the food supply system, led to the expression “Meadows are mother of crops” (Lagerkvist, 2004; Lennartsson & Westin, 2019b).

Not only were the meadows an important source for animal feed, but also a source of community and an important part of shaping culture. The meadow and its management practices had a vast impact on the organization in society, steering were humans lived, how they spent their time, and their access to food. It also had cultural and religious importance to society. The agricultural societal shift led to increased population growth, as more people could be fed. Up until mid-19th century increased population had led to intensive increase of land transformation occurring in such extent that by the end of the century the possibilities for new land to be shifted into agricultural land was challenging, and many meadows were transformed to arable land. This also had a second effect – that the animal feed was not meeting the needs, hence the animal population stagnated and so did the natural manuring. Around the 20th century Sweden shifted to an industrialized country, also industrializing the agricultural system and to further extent using man-made fertilizers. During this period to meadows continued to decrease in favor for arable land, as meadows lost their status as mother of crops (Lagerkvist, 2004; Lennartsson & Westin, 2019b).

During the late 20th century and after, mowing at lake meadows is primarily done with cultural and nature conservation aims as the historical management practices has, during the hundreds or so years of maintenance, developed into a unique environment with high values of flora and fauna (Lagerkvist, 2004; Lennartsson & Westin, 2019b).

3.2. Classification of lakes

According to SMHI, Swedish Metrological and Hydrological Institute, more than 369 000 water bodies can be found in Sweden, whereof 103 000 lakes are registered in SVAR (Svenskt Vattenarkiv) (SMHI, 2022). Of the total area of the country, approximately 85% consist of land, 10% of ocean and 5% of lakes and inland water (SCB, n.d.-b). Based on the water quality and surrounding environment, different animals thrive in and in connection with a lake. The vegetation which can be found in the lake zone, water compartment and on the bottom of the lake also varies. Lakes are classified based on these different conditions and the following section gives a brief description of the different types of lakes (Naturvårdsverket, 2000).

3.2.1. Oligotrophic plain lakes (3110)

Oligotrophic plain lakes are shallow lakes which have few minerals and are poor in nutrients (< 12.5 µg P/l), have clear water and clay or gravel bottom. They usually have a limited reed growth in lake meadows. They can be found throughout the whole country, but mainly occur in coniferous forests, and is surrounded by sand, moraine, or mountains. The vegetation in the lakes is often also sparse, and this in combination with sandy soils exposes them to acidification. Regulation of water levels in these types of lakes have a very negative effect on the fauna, since it can cause both soil erosion, affect the possibility for fish to migrate and lead to overgrowth of the lakes (Naturvårdsverket, 2011e).

3.2.2. Oligo-mesotrophic lakes (3130)

"Oligo-mesotrophic lakes with vegetation Litteralletea and/or Isoeto-Nanonjunctea" (Ävjestrandssjöar) are shallow lakes which are either poor, or relatively poor in nutrients (< 25 µg P/l). They can be found throughout the whole country, but mainly occur in flat areas/plain lands. Reed growth in lake meadows is usually limited and lake zones are kept open trough ice affecting extensive growth/ice shearing and/or grazing. More dense vegetation can however occur in bays which are protected from weather and animals. In case of upstream agricultural land, and/or forest management in connection with the lake, increased amount of nutrients and soil erosion causing hummus in the lakes can be expected, which will have negative effects on the status of the lake. Managing lake meadows in agricultural intensive areas with animal grazing or harvesting of reed, may be a precondition to maintain biodiversity and keep a good status of the lake (Naturvårdsverket, 2011c).

3.2.3. Hard oligo-mesotrophic lakes (3140)

"Hard oligo-trophic lakes with bentic vegetation of charophyte" (Kransalgsjöar) mainly occur in Uppland, Södermanland, Jämtland, Skåne and Gotland. As for oligo-mesotrophic lakes, the total content of phosphorous in the water shall be below 25 µg P/l, but due to calcareous conditions for this nature type, the lakes are dominated by charophytes and other vegetation thriving in calcareous water. As for most lakes, they are under the threat of being regrown by e.g. reed, due to eutrophication, anthropogenic influence of water levels and/or ceased usucapion of lake meadows (Naturvårdsverket, 2011d).

3.2.4. Natural eutrophic lakes (3150)

Natural eutrophic lakes can be found throughout Sweden, but the majority of the lakes are located in the southern parts of the country and most commonly on plain land and close to agriculture areas. They are characterized by being naturally nutrient rich (> 25 µg P/l), alkaline (pH > 7), often with clay sediment, and by having a diverse fauna of plants, herbs, and animals. The nature type poses a risk for eutrophication when exposed to run-off from upstream agricultural land, which can lead to algae blooming, oxygen free aquatic environment and regrowth (Naturvårdsverket, 2011b; Vattenmyndigheten, 2011)

Eutrophic lakes in the alpine region, are estimated to have favourable conditions and expected to stay viable in the long-term. According to the Swedish Environmental Protection Agency, natural eutrophic lakes in boreal and continental regions are however classified to have insufficient status, where many lakes have high growth of algae and monoculture reed populations spreading in the water area. Managing lake meadows, with animal grazing or harvesting of reed, to keep a good status of the lake, is relevant also for these types of lakes. Forestry in connection with the lake may also have negative effects, since intensive land use (logging, transportation, ditching, etc) increase soil erosion and run-off to the lake. Furthermore, changing water levels, emissions from a point source and introduction of foreign species may have negative effects (Naturvårdsverket, 2011b).

3.2.5. Natural dystrophic lakes and ponds (Bog lakes) (3160)

Bog lakes (myrsjöar) are small lakes in coniferous forests and areas rich in mosses and can be found from north to south of Sweden except on the bare fjeld. They have brown water due to high content of hummus and peat, low content of nutrients ($P < 25\mu g/l$) and naturally low pH, which makes them sensitive to acidification. Other anthropogenic impacts, such as emissions from point sources and changed water levels due to e.g., ditching poses a threat the flora and fauna in these nature types (Naturvårdsverket, 2011a; Vattenmyndigheten, 2011). Extensive reed growth in lake meadows does, however, not seem to be a major problem in bog lakes.

3.3. Regrowth of lake meadows

The lakes which mainly poses a risk for regrowth are eutrophic lakes. These can either be naturally eutrophic lakes, or lakes which are eutrophic due to external impact, e.g. nutrient runoff from upstream agricultural land, influence on water levels in the lake, forestry in connection with the lake or point source emissions. (Naturvårdsverket, 2000; Vattenmyndigheten, 2011).

Several types of reeds and sedge grow in freshwater lake meadows. The type of species thriving in these wet conditions are adopted to grow in the oxygen poor conditions/sediments which exist in wetlands, among others due to them having hollow stems that provides oxygen from the air down to the root system (Lennartsson & Westin, 2019a). Low-growing species of grass and sedge occur in areas which are maintained/claimed, but when the use of the land ceases high-growing, more invasive flora, such as common reed, reed canary grass, and cattail normally outcompete other vegetation (Carson et al., 2018; Finish Food Authority, 2017). Furthermore, if the beaches are not claimed and the reed is not removed through grazing or harvest, the plants wither and becomes litter on the lake bottom and in the meadow, and consequently the ground level in the lake slowly raises creating larger meadows and less open water area (Lennartsson & Westin, 2019a). Shallow lakes which are open from regrowth is a pre-condition for several birds to come back each year to a location instead of choosing other lakes for their yearly bird nesting (Feuerbach et al., 2014).

Regrowth of lakes is a natural aging process and does not only have negative effect on the biodiversity in lakes. They also provide protection to wildlife such as cover for bird nests, feed for animals, and act as host plants for certain insects (Feuerbach et al., 2014).

Error! Reference source not found. shows a lake meadow at lake Tydjesjön in January, with laying reed canary grass and acute sedge (in front), and common reed standing (at the back of the photo). Common types of vegetation causing regrowth of lakes, including the three mentioned above, are further described below.

Figure 1. Lake meadow, Tydjesjön, 2023-01-30

3.3.1. Common reed – Phragmites australis

Common reed is a perennial plant in the grass family. The plant can be found in salt, brackish and freshwater wetlands, and is distributed all over the world except for in the mountain regions. The straws are thick and steady and normally reach between 1.5 and 5 meters. It has invasive characteristics where it easily spreads and creates large monoculture beds. The root systems of the plants are big and consist of rhizomes which form new sprouts/nodes in autumn, stretching 10 to 15 meters. Seeds also spread with the wind (possibly additionally with birds) during the winter season. In springtime new sprouts grow and the reed reaches full height in the end of July (Cubars & Noviks, 2012; Granéli, 1984).

After the growth period, the plant above ground withers and the leaves falls off. The stems and panicles of the plants, however, remain standing during the winter and thus protect new shoots as they grow up in the beginning of next season. They also act as oxygen suppliers for the new sprouts, since the hollow old stems can provide oxygen down to the roots in the sediment. (Granéli, 1984; Våtmarksguiden, n.d.-a). In eutrophic conditions, and when the common reed is not controlled by grazing, and/or ice shearing it has the possibility to spread up to 1 meter in coverage circumference per year and outcompete other vegetation in the area (Våtmarksguiden, n.d.-a).

Figure 2. Common reed, artfakta, © Johan Cejie, Uppsala

3.3.2. Reed canary grass – Phalaris arundinacea

Reed canary grass is a perennial grass and reaches 1.5 to 2 meters at full height. In the wild, it most often grows in wet areas (such as lake meadows) but the grass can also grow in more dry conditions. It is additionally used for cultivation, previously mainly for animal fodder, and today utilized for its rich energy content for biogas production. According to Rörflenodlarna, 1 ha of reed canary grass produces 5-8 tons of crop, or 15 to 35 MWh (Rörflensodlarna, n.d.; Våtmarksguiden, n.d.-d). The reed canary grass spreads through nodes shooting out horizontally from the roots. They also reproduce to some extent with seeds.

Figure 3. Reed canary grass, Artfakta, © Mats Bergquist, Boden

3.3.3. Cattail – Typha

Cattail includes a large family of species which grows in wetlands in all regions of the world, except for Antarctica. The plants grow rapidly, adapts to environmental changes, and can withstand periods of floods or droughts, making it competitive against other vegetation (Bansal et al., 2019). The plant is rarely grazed by animals but can become extinct by regulating the water levels in the lake; lowering the water and cutting the plants, with a subsequent water raise which prevent further growth. Broadleaf cattail/bulrush/common cattail have invasive characteristics. Common for all cattail is that they have positive effects on biodiversity as well as takes up nutrients and counteracts eutrophication in lakes (Våtmarksguiden, n.d.-c).

Figure 4. Cattail, Artfakta, © Mirjam Ideström, Norrköping

3.3.4. Great mannagrass/Reed sweet grass – Glyceria maxima

Great mannagrass was introduced in Sweden in late 18th century for fodder reason but has now spread to a variety of wetlands in mid and south of the country. Like common reed, it has invasive characteristics and is in many areas a threat to the local biodiversity. It grows in large beds, germinates rapidly and easily outcompetes more sensitive species. It also has some positive effects for local ecosystems; the plant takes up nutrients and heavy metals and therefore have the possibility to act as a water purifier in eutrophic and contaminated lakes (Våtmarksguiden, n.d.-b).


Figure 5. Great mannagrass, Artfakta, © Carl-Johan Månsson, Gullabo

3.3.5. Acute sedge/Slender tufted sedge - Carex acuta

Acute sedge belongs to the family Carex, a plant family with several different sedges, whereof around 100 species can be found in Sweden. Sedges in general can be competitive after they have established in a new place, but it takes time and therefore they mainly appear in mature wetland with a diverse flora (Våtmarksguiden, n.d.-e). Little information can be found regarding the acute sedge specifically, except that it is spread in the whole country, mainly in the southern part, and grows along freshwater lakes and in wetlands on organogenic sediment soils.


Figure 6. Acute sedge, Artfakta, © Per Lagerås, Lund

3.4. Management practices for restoring and maintaining lake meadows

Managing a lake meadow well can have a positive impact on biodiversity nearby. Which management practices are used around lakes have a profound impact on the nearby environment. Not only does the practices impact vegetation on land, but also water quality and surrounding biodiversity (de Jong, 2009). Well managed meadows along lakes can benefit amphibians, due to the temperature rise in the blue boarder, and mosaic landscape along the lakes benefit waders. Reed also takes up nutrients leaching from nearby arable land, hence decreases their release into water and eliminates them from the water system during time of harvest (Degerman et al., 2008; Komulainen et al., 2008a).

3.4.1. Mowing

Mowing is the management practice of cutting biomass with the primary aim for it to be used as fodder for cattle. It may also be used for lake restoration purposes. A scythe or a knife mower (like rotary mower or tractor driven machine for harvesting) is mainly used, with the positive effect that it leaves a clear cut and thus avoids breaking the valuable flora which potentially could lead to drying. Mowing is good for seed germination, and if the biomass is removed after harvest, the seed growth will also be good, benefitting floral biodiversity in the meadow. When the aim is to restore the lake meadow, timing of mowing is of high importance for the effect it will have. It is therefore important to find the best timing in relations to seed periods but also birds nesting seasons (Lagerkvist, 2004; Lennartsson & Westin, 2019b).

Mowing around lakes can be challenging as the ground could be very wet, leading to difficulties transporting and managing the mowing machines (if used). One should note that machines for harvesting lake meadows are under development, hence the machines used today can be seen as temporary technical solutions that further needs to be improved to decrease costs and increase efficiency (de Jong, 2009; Lagerkvist, 2004). Most used in these type of wet lake surroundings, with relatively good results, is piste machines adapted to summer conditions (Wahlström, 2023).

3.4.2. Grazing

Grazing is the management practice of letting grazing animals feed from the biomass, consuming it directly. The animals impact the vegetation both by consumption, but also by physical movement on the land as well as by natural fertilization. Grazing generally leads to a lower seed germination, however the ones spread have good opportunities for growth. Grazing also leads to the land being interchanged in a mosaic structure, which specifically gains birds nearby the lakes by the interchanging high and low raised vegetation. The time for grazing is limited, and in the area of Tydjesjön and similar geographic areas, it is approximately 140 days per year. The time is concentrated to late spring, summer, and early autumn period, from May to October in best cases (de Jong, 2009; Lagerkvist, 2004; Lennartsson & Westin, 2019b). The best time for grazing, when the aim is to restore and manage lake meadows, is early autumn when the high grass already has been removed, as this leads to the animals grazing closer to the shoreline and the reed (Pettersson, 2023).

Cattle are the animals most used for grazing around lakes. They graze in spots and have the ability to graze reed standing in water, up to one meter water of depth. Cattle can contribute to a blue boarder ("blå bård") being created, which in practice means the reed growth being moved further out in the water leaving a shallow water strip between the reed and land. The blue board is a protected environment where fry can grow, but the board is also appreciated by insects, birds and amphibians (de Jong, 2009; Lagerkvist, 2004).

Sheep can also be used for grazing nearby water streams, however, they do so very selectively and may therefore not reduce the reed beds. Horses are less selective in their grazing and can, like cattle, also graze reed while standing in water. Neither sheep nor horses are effective to graze in these areas alone, however it is favourable in combination with cattle (Lagerkvist, 2004).

In shallow wetlands there are challenges with the parasite Common liver fluke (Fasciola hepatica), which can lead to liver failure and decreased growth of the cattle. In general, no symptom is seen, however, severe cases can cause abdominal pain, edema as well as sudden death. The common liver fluke is found in areas with high precipitation in southern and western parts of Sweden, and the cattle is infected by parasite-contaminated feed and water. A growth in diseased animals has been seen in the past years, however, the number is still considered to be low in the region. The reason for increased growth of the parasite can be linked to climate change, as increased temperatures favor the parasite, increased and longer grazing, but also by the increased use of wetland grazing. This risk can be decreased by interchanging management practices, for instance alternating with mowing or burning in periods (Lagerkvist, 2004; Novobilsky et al., 2012; *Statens Veterinärmedicinska Anstalt*, n.d.).

Another grazing animal suitable for wetlands is water buffalo. They have broad hoofs helping them to move in wetlands, and often mud bath which causes mud puddles, appreciated by birds and amphibians. The buffalos can manage to graze in water, swim and graze on deep water, as well as dive to graze rhizomes, roots and reed below water. Their grazing can help restore overgrown lakes, not only grazing from land, but also clearing the lakes deeper areas without help from machines. Water buffalos have been tried for restoring wetlands, in for instance Fysingen nature reserve, and shown to be beneficial to biodiversity. Wetland birds and amphibians thrive in buffalo grazed areas. According to the country board this method is both simpler and cheaper compared to mechanical mowing (*Länsstyrelsen Stockholm*, n.d.; *Miljö & Utveckling*, n.d.). Exposing reed to continuous grazing by graylag geese and Canada geese, which feeds from the new sprouts, also has the possibility to reduce the reed beds to a high extent (Våtmarksguiden, n.d.-a).

Figure 7. Water buffalos grazing in Fysingen nature reserve (Dagens Nyheter, 2020)

3.4.3. Mowing and grazing

A combination of the above two management practices, mowing and grazing, is common. Historically land has often primarily been mowed and after that grazing animals have been used to further graze the area. While mowing became a less reasonable management practice in land management, grazing took over in clearing land. Not uncommonly, there are lack of grazing animals nearby the lakes and river sides, leading to the return of mowing (Lagerkvist, 2004). In the case of Tydjesjön, there are grazing animals adjacent to the lake, however the number of grazing animals is not enough to properly clear the lake meadow from reed and other vegetation (Wahlström, 2023).

The combination of mowing and grazing is however preferable, since it effectively removes biomass at a larger pace during mowing and is combined with grazing that further minimizes growth and could lead to a blue border. Grazing also has the possibility to remove vegetation in areas where mowing is not technically possible. Another benefit is also related to the floral biodiversity, as seed dispersal is favoured by mowing, and grazing promote seed growth (de Jong, 2009; Lagerkvist, 2004; Lennartsson & Westin, 2019b).

3.4.4. Harvest

A fourth management practice is to harvest, cutting and clearing the land mechanically. This can be done in a similar way as mowing, either with scythe or knife mowers, however challenges may occur in very wet areas. In some specific case studies pontons and special constructed wetland machines, such as crawler tractor with bale press attached, have been used to cut the reed. With this management practice the biomass is removed from the land with the aim of using it for other purposes. However, this requires high yield to be financially motivated. Timing for cutting the reed is important, in order to ensure high yields and energy content in the biomass, but also to minimize disturbances for nesting birds. Case studies in the wetlands of Albäcksån have been made with cutting in august, however insecurities remain of how the biomass yield and energy content is affected, i.e. possible decreased, if done annually (Prade et al., n.d.). For further information regarding time for harvest, see Section 3.6.

3.4.5. Burning

Burning is the management practice with least vegetational impact. This practice weakens the vegetation, which benefits grazing after growth, however, does not lead to a decrease of growth coming season (Lagerkvist, 2004).

3.4.6. Ice shearing

In northern regions, shallow lakes and rivers can freeze in winter. The frozen water and sediment harm the reeds rhizome and roots, thus hinders its growth coming season. The lake Tydjesjön is located in a part of Sweden where ice shearing could happen (de Jong, 2009; Lagerkvist, 2004). However, this method is relying on surrounding weather, not possible to control nor impact.

3.4.7. Adjusted water levels

Another management practice that can be used to minimize reed growth is to adjust the water level of the lake. This functions well, particularly in shallow lakes which can either be increased or decreased, and in both cases the reed growth is highly impacted. This is in general a cheap and fairly simple management method. Draining or flooding a lake could decrease the growth of reed and facilitate the area for mowing. These management practices are a way to weaken reed growth. Draining can for instance be done once per season without damaging the ecosystem as such, since small lakes often are adapted to seasonal droughts. The same applies to flooding, as this can regenerate the system benefitting the habitat for fish, birds, and amphibians. Flooding needs to be monitored carefully, as it does not only impact the lake, but could possibly have negative impacts on the surrounding buildings and agricultural lands, as well as lead to a decrease of aquatic vegetation (Degerman et al., 2008; Lagerkvist, 2004).

3.5. Management techniques for lake meadow biomass

Reed is globally spread species of plants that has been used by humans all over the world for centuries. It is still today an important plant for humans, nowadays increasing in potential for it being a renewable resource possible to use for energy production without competing with food production land areal (Köbbing & Zerbe, 2013). Reed also has multiple other potential end-uses which can be further read about in below chapter. Reed is bulky, hence requires larger spaces for transport and storage in comparison to other bio raw materials used for energy use. This factor makes it important to manage the supply chain within a small radius to make the biomass use economically sustainable.

3.5.1. Composting

Composting is a controlled biological process where microorganisms break down the organic matter into a smaller component more available to the soil. This process appears in nature regardless of human interference, however if managed in a controlled way with optimized conditions, it leads to a quicker decomposition and the compost quality is more homogenous. Prior to a controlled composting process the biomass should be chopped for quicker decomposition. When using aerated, turned, windrow composting the biomass is placed in characteristic long piles which are turned regularly. For controlled windrow composting, it lasts around 8-16 weeks, primarily depending on raw material used, amount of turns and the wanted output. The process releases carbon dioxide, methane as well as nitrous oxide during the decomposition process. It is important to turn the biomass frequently, and not to have the windrow to wet as oxygen is needed to avoid an anaerobic digestion, with unwanted increased methane emissions as a result (Chen et al., n.d.; Michel et al., 2022; *United Stated Environmental Protection Agency*, n.d.).

The end-product is compost and can be used for soil improvement, and lake meadow biomass should be harvested in late summer when used to produce compost products (van der Sluis et al., 2013).

There are also possibilities to use reed without any other treatment than mechanically chopping it to small pieces before spreading it on the fields. This method is simple, but not so efficient for nutrient uptake, thus rarely used. Another way to use reed for fertilizing is to mix reed with compost waste, enabling an easier nutrient uptake for the crops (Köbbing & Zerbe, 2013).

3.5.2. Incineration

Incineration is a thermal treatment that can be used to recover energy from the treated material. In a controlled combined heat and power plant, CHP, the reed is combusted at high temperature with an outcome of electricity and heat, where the majority of the heat generated can be used for district heating (Demirbas, 2011). Challenges in combusting lake meadow biomass is linked to formation of ash, as this biomass, especially common reed, contains high share of ash (approx. 4% up to 10%). The ash causes a problem during combustion, as heat value is lowered and hinders combustion and flues as well as causes environmental problems (Komulainen et al., 2008a).

The biomass must have a low moisture content before incineration. The optimal time for harvest is during late winter, suggestibly March-April, where the moisture content is low. This is also favourable as ash content is lower at this time (2-4%), due to the minimized number of leaves attached to the harvested biomass. If harvest is performed at another time of the year, the moisture content will be higher, leading to an additional heating process being added prior to combustion (Köbbing & Zerbe, 2013; Komulainen et al., 2008a).

Using biomass as an energy source has many advantages. It decreases greenhouse gas emissions compared to if fossil resources are used to produce electricity or district heating. It is also a more local resource, giving regions and countries more security and self-sufficiency when it comes to energy production (Komulainen et al., 2008a). The whole plant, including stem and leaves, can be used when producing energy from reed. As density of energy is decreasing in a bulky biomass product, so must also the transportation distance. To manage this, the bulky biomass can be split up and compressed into other forms such as bales, briquettes, and pellets, which increases the density vastly (Köbbing & Zerbe, 2013).

3.5.3. Anaerobic digestion

Anaerobic digestion process is a bacterial fermentation process which converts organic matter into biogas and digestates. The organic raw material can come from different types of biomasses, for instance straw, sawdust, and reed. The process occurs without access to oxygen, at a temperature range between 10 and 71ºC and the produced biogas consists of primarily methane and carbon dioxide. The anaerobic digestion process also produces solid and liquid digestate (which can be used as soil-improvers). Further, the biogas can be purified in an upgrading process, separating most of the carbon dioxide from the biomethane, leaving it with over 90% purity. This biomethane can then be used as biofuel in vehicles or used as feedstock in industrial processes. If the biogas is not upgraded, it can be used for district heating. The carbon dioxide removed during the biogas upgrading process can in turn be used in various industrial processes, e.g., methanol production (Ahlgren, 2001; Demirbas, 2011).

Reed for biogas production should preferably be green mass harvested during late summertime (August – October) (Köbbing & Zerbe, 2013), this due to respect of the birds nesting season, but also to maintain further growth for coming harvest and to maximize nutrient content. Another benefit with harvesting in late summer season is that the nutrients are removed from the water with the reed before transferred to the rhizome (Köbbing & Zerbe, 2013; Komulainen et al., 2008a).
To use reed for biogas production, it is preferrable to chop the material prior to use, as it increases the reactivity of the surface. Challenges do occur in harvesting summer-reed, as the access to the reed can be hindered by high water levels and nature conservation aspects. Leftover sludge from the anaerobic process can be used in agriculture as fertilizer (Komulainen et al., 2008a).

3.5.4. Pyrolysis

Pyrolysis is a process where chemical decomposition of organic matter occurs. The process is done by heating the matter in an oxygen-free environment. This environment leads to a vast amount of the carbon is concentrated in end-products with high carbon content. The process is spontaneous at very high temperatures, normally above 300ºC, but varies depending on input material. The temperature can also vary and as such does also the outcome and carbon sequestration, which leads to possibilities to adjust the process based on wanted outcome. Pyrolysis of biomass products results in gaseous products (for instance CO_2 and CH_4), liquid bio-oil, solid biochar and small amounts of water (Verheijen et al., 2010).

Temperature and heating speed in the pyrolysis process have the highest influence on the yields of each end-product. Most commonly a temperature between 500-800°C is used in the process. Lower temperature and long reaction time however results in higher yields of solid biochar (Abhijeet et al., 2019).

Biochar, which is the solid product created during pyrolysis, can be used for multiple purposes, among them to produce heat and power and for agricultural use. Interest for biochar is increasing as this could be a method to capture carbon and replace use of fossil fuel in several applications (Weber & Quicker, 2018). For the agricultural purpose the biochar application increases soil fertility by improving nutrient and water availability and could potentially be a carbon sink (Verheijen et al., 2010).

Carbon content has been found to be higher in reed during winter season compared to in summer (Carnevale et al., n.d.) and therefore a harvest in winter or early spring should be beneficial for biochar production.

3.5.5. Other management techniques and end-uses

Historically, reed has had an important impact in society and been used as feed. It has been used either directly by grazing animals, during spring and summer, or as fodder for winter feed after harvest. Still, these methods are used and play an important role in providing fodder for animals, specifically suiting ruminants. The nutrition content is slightly lower in reed compared to other fodders; however, its cheap price and broad availability is a benefit (Köbbing & Zerbe, 2013). The reed should be harvested in early summer, when the reed plants are young, to get the best quality for fodder uses (van der Sluis et al., 2013).

In Northern Europe's ancient times and for as long as up until late 19th century reed was commonly used for roof thatching, a method of constructing a layered roof with reed straws keeping the inner roof dry and insulated (Köbbing & Zerbe, 2013). Reed is also used in Europe in housing and in the construction industry. The insulation properties make it suitable as insulation material in walls and roofs, and also for the production of wall panels. It is also extensively used as garden fences, blinds and coverings (Köbbing & Zerbe, 2013).

Reed can be used instead of wood for production based on cellulosic content. The cellulosic content of reed can be used for pulp production (raw material in paper), although it is often necessary to blend with other longer cellulosic fibres for increased strength properties. Pulp made of reed can also be used to produce polymers, for bio-based plastics or textile fibers (Köbbing & Zerbe, 2013).

3.6. Harvest time based on end-use and purpose

Harvest of reed may be performed during the whole year but based on the end-use or purpose of the management, different time periods are preferred. For biochar production and incineration, winter or early spring is ideal, since the reed then has a high carbon content (pyrolysis) (Carnevale et al., n.d.) and lower amount of ash is created during incineration (Köbbing & Zerbe, 2013; Komulainen et al., 2008a). During the early growing season, as the reed is young, the best fodder quality is attained. Restoration with the aim to prevent growth next-coming year should also be performed in the spring before blooming and further seed spreading (van der Sluis et al., 2013). During summertime, the reed takes up high amounts of nutrients, which are recovered back to the roots in autumn/winter, and hence a harvest in late summer/early autumn is needed to remove excess nutrients from the lake. Also harvest for biogas is best performed during late summer to get a maximum nutrient content in the biomass (Niemiec et al., 2019). Figure 8 shows an overview of harvest time during the year based on purpose and end-use.

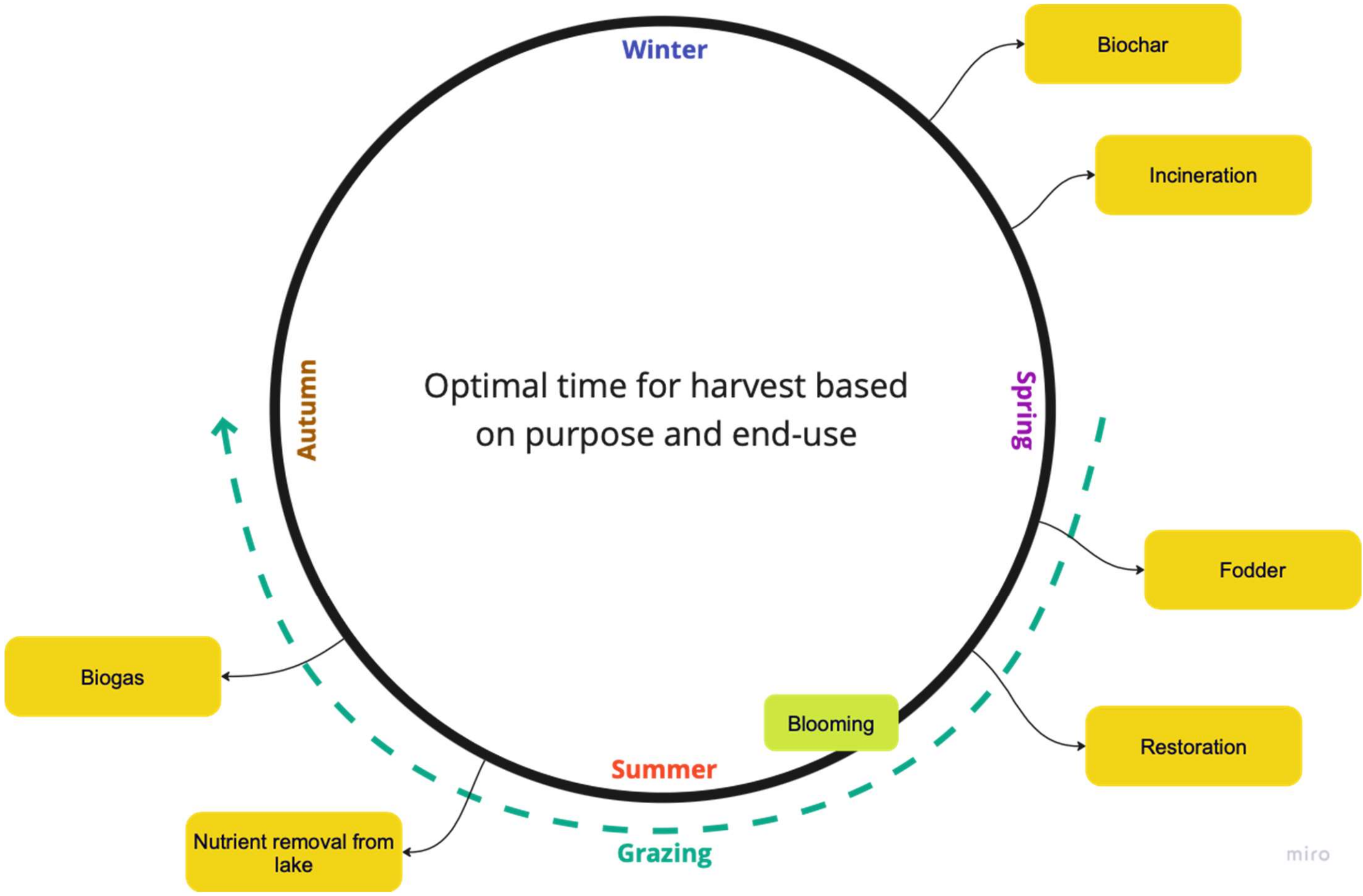

Figure 8. Optimal time during the year to harvest reed based on purpose and end-use.

3.7. Fundings and financial support for restoration and management

Lokala Naturvårdssatsningen (LONA) is a funding available for municipalities or non-profit organizations that want to implement projects concerning wetlands restoration and conservation. Fundings for wetlands restauration, with the aim to, e.g., benefit biodiversity or decrease greenhouse gas emissions, can be granted for 90% of the total costs. Other projects, such as nature maintenance and conservation, can be funded with up to 50% of the costs (Länsstyrelsen, n.d.-a). Already ongoing maintenance, for example if a lake meadow is today sustained through grazing or mowing, is however not eligible for grants (Naturvårdsverket, n.d.-c). LONA is therefore only relevant for initial restoration in overgrown lakes, while the continuous management of lake meadows must be financed in other ways. Private landowners can be an actor within the project but not an applicant themselves.

Lokala Vattenvårdsprojekt (LOVA) can be applied for measures focused on marine and freshwater environment. It is possible to apply for fundings covering up to 90% of the costs, for projects with the aim of decreasing eutrophication and nutrient leakage into lakes. LOVA could therefore in theory be relevant for lake meadow restoration, but it is not possible to get a grant for projects which is already ongoing. As for LONA, private landowners can be an actor within the project (Länsstyrelsen, n.d.-b).

Fundings relevant for lake meadow restoration and maintenance can be applied for through the Swedish Board of Agriculture by private landowners. Financial support is also available for investment in biogas facilities, but fundings are only granted for facilities producing biogas from manure, i.e., not for harvested reed (Jordbruksverket, n.d.-a). Fundings for maintenance of wetland and ponds, with the aim to prevent regrowth, nutrient leakage or loss of biodiversity is compensated with 3 600 SEK/ha and year. Funding can be paid in advance, partly during the project period or in arrears. A precondition is then that the wetland or pond has either already been restored or is a constructed wetland, and that it has previously been approved by the County Administrative Board of as important from an environmental point of view (Jordbruksverket, n.d.-c).

For funding from the Swedish Board of Agriculture, the private landowner contacts the County Administrative Board advisors for support prior to the application process, where the scope of the project is set as well as an evaluation of the possible biodiversity gains and specific values are done. Application is done at the Swedish Board of Agriculture SAM internet platform. The landowner receives an annual project plan to work towards, for instance mentioning actions to take, species to preserve etc. After the project period is over, a case handler from the County Administrative Board visits the project site to evaluate the results based on parameters such as if there are any red-listen species within the area. If the area is considered to have specific value, then the compensation is further increased to 6 000 SEK/ha and year (Bäckström, 2023; Fredriksson, 2023).

3.8. Legal framework for lake meadows and lakes

The Swedish Environmental code, 1999, is a key legislation containing 15 acts and fundamental rules of environment both in water and on land. Some restorations and actions linked to lake meadows are restricted by the environmental code, and therefore needs thorough control prior to starting. Some cases of restorations are not restricted but requires consultancy with the local country administration to get approval for actions planned during restoration, making sure it is not harmful for the local environment. If the lake meadow is owned by several different landowners, then an agreement with each landowner needs to be in place in order to restore (Degerman et al., 2008).

3.8.1. Protected nature

Sweden has several areas of protected nature, 28 national parks as well as more than 2 500 nature reserves areas, covering almost 10% of the country's land area. Depending on the aim of reservation for these areas, the possibility to manage land needs authorization, might be restricted and can also intrude in the ownership of the landowner. The case study lake Tydjesjön is not a protected nature area according to the Swedish Environmental Protection Agency's tool "Skyddad Natur". This tool shows areas protected, as well as which type of protection is applied in the specific case (Degerman et al., 2008).

3.9. Lake Tydjesjön, a case study

Lake Tydjesjön is a 0.8 km^2 large, shallow, plain lake located on in Åmåls Municipality in Dalsland, within the region of Västra Götaland (Länsstyrelsen, n.d.-c). The lake is well-known for its rich birdlife with whooper swan, great crested grebe and western march harrier being examples of species which return annually to the lake for brooding (Turistrådet Västsverige, n.d.). Tydjesjön is supplied with water mainly from Vitlandaån and the water from the lake is discharged via Forsnäsån into Vänern. The water level in the lake has been lowered at some point in time, but information regarding when this occurred has not been found (Jansson, 2013).

According to the Swedish Environmental Protection Agency's guide to "Swedish nature types in the habitat directive" (NV-04493-11), the distribution area of oligo-mesotrophic lakes includes the area where Tydjesjön is located (Naturvårdsverket, 2011c). Today, Tydjesjön is however eutrophic with a high content of nutrients in the water due to leakage from upstream agricultural land (Hultengren & Karlsson, 2018; Wahlström, 2023).

The area surrounding the lake is owned by approximately 20 different landowners, and mainly consist of a mixture of agricultural land/fields, production forest and some areas of natural forest and natural pastures (Länsstyrelsen Västra Götaland & Skogsstyrelsen, n.d.). The lake meadows surrounding the lake have, in similarity with other lake meadows, historically been managed by the landowners for its fodder resources (as hay meadows and for grazing) (Länsstyrelsen Västra Götaland, 2022). Today, a shorter distance along the lake is grazed, but most of the lake meadows are unmaintained which has resulted in a flora dominated mainly by reed and sedge (acute sedge/slim sedge, reed canary grass and common reed). Fewer birds, especially waders, also return for brooding compared to when the lake area was maintained (Wahlström, 2023).

The areas in the lake consisting of vegetation, and the overgowth during the last 80 years can be seen in **Error! Reference source not found.**.

Map Tydjesjön (open water in blue, water with vegetation in blue striped) *Air view today* *Air view app. 1960*

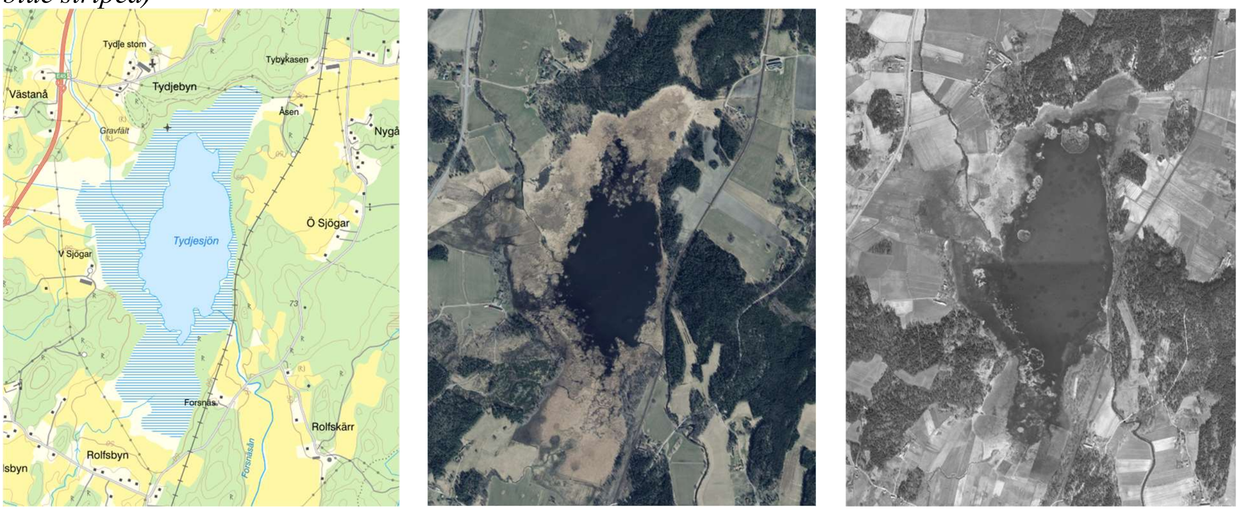

Figure 9. Map and photos retrieved from Lantmäteriet (Min karta https://minkarta.lantmateriet.se)

Error! Reference source not found. shows a restored area maintained through grazing (closest in photo) and a regrown lake meadow dominated by common reed (in the back). The area in between is dry laid in periods, and the grass tufts visible on the surface has been grazed by cattle during pasture (Wahlström, 2023).

Figure 10. Lake Tydjesjön, 2023-01-31

Figure 11. Whooper swan, Tydjesjön, April 2023 (photo Daniel Grip)

Figure 12. Tydjesjön, April 2023 (Photo Daniel Grip)

4. PRESENTATION AND DISCUSSION OF RESULTS

4.1. Climate impact

4.1.1. Flowchart

Figure 13 provides an overview of the processes and biomass flows which have been used in the calculations for the different scenarios. Boxes in white displays the products which are assumed to be replaced when using lake meadow biomass as an alternative resource.

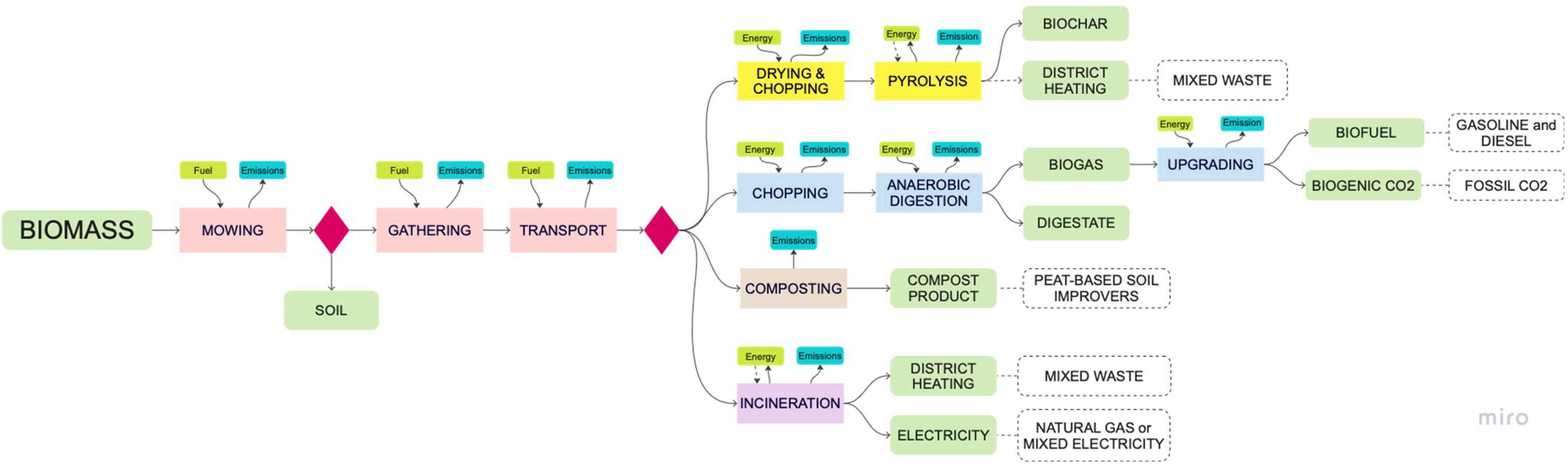

Figure 13. Flowchart biomass flows

4.1.2. Greenhouse gas emissions and carbon flows

Table 1 presents the greenhouse gas fluxes for the assessed scenarios. The numbers are presented in $kgCO_2e/tDM$ (GWP100). Figure 14 to 19 illustrates the carbon flows in each system, and the uptake versus release of greenhouse gases per process step, with the biogenic carbon dioxide illustrated in green and the fossil carbon dioxide in black.

Table 1. GHG savings using lake meadow biomass (kg CO2e/tDM, GWP100)

	PS	ND	M	B	T	C	I	AD	PY	SUM
1. Mowing (BAU)	- 1661	+ 1495	+ 32							**- 134**
2. Compost	- 1661		+ 32	+ 9	+ 2	+ 1557				**- 61**
3. Incineration, case 1	- 1661		+ 32	+ 9	+ 2		+ 1189			**- 429**
3. Incineration, case 2	- 1661		+ 32	+ 9	+ 2		+ 1406			**- 211**
4. Anaerobic digestion	- 1661		+ 32	+ 9	+ 2			+ 737		**- 881**
5. Pyrolysis, case 1	- 1661		+ 32	+ 9	+ 2				+ 759	**- 859**
5. Pyrolysis, case 2	- 1661		+ 32	+ 9	+ 2				+ 1019	**- 599**

(PS=Photosynthesis, ND=Natural decomposition, M=Mowing, B= Baling/Collection of biomass, T=Transport, C=Composting, I=Incineration, AD=Anaerobic digestion and biogas upgrading, PY=Pyrolysis, SUM=Total greenhouse gases to/from atmosphere.)

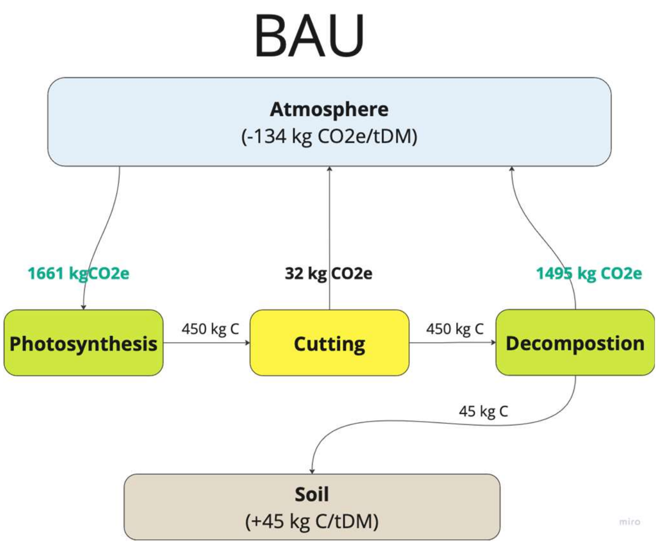

Figure 14. Flowchart BAU (Mowing and leaving the cut biomass on site).

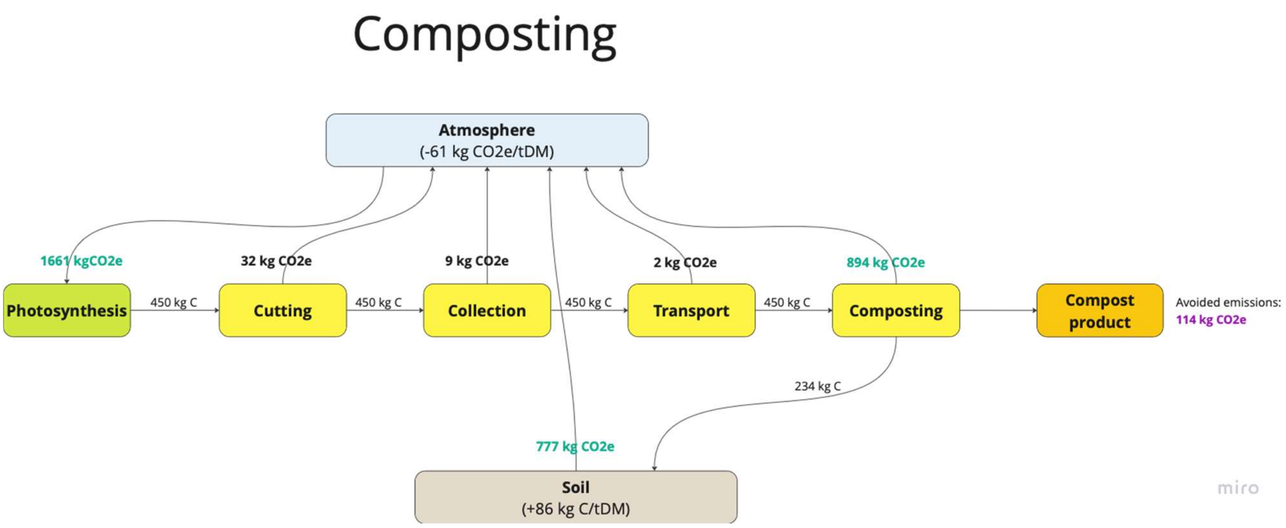

Figure 15. Harvest and composting at an external site.

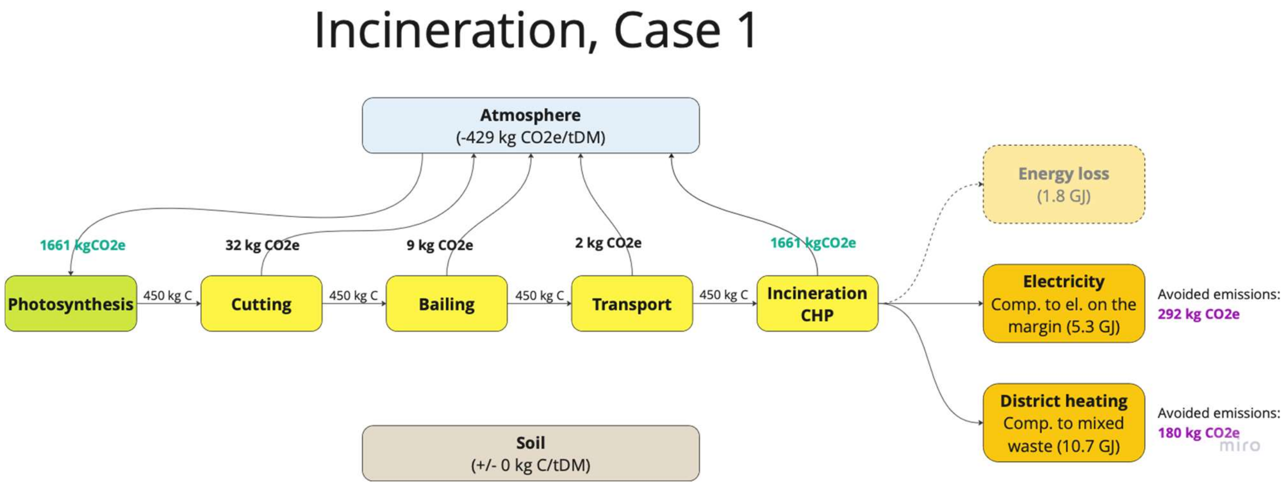

Figure 16. Harvest and treatment in a CHP plant, with electricity produced replacing electricity on the margin (natural gas).

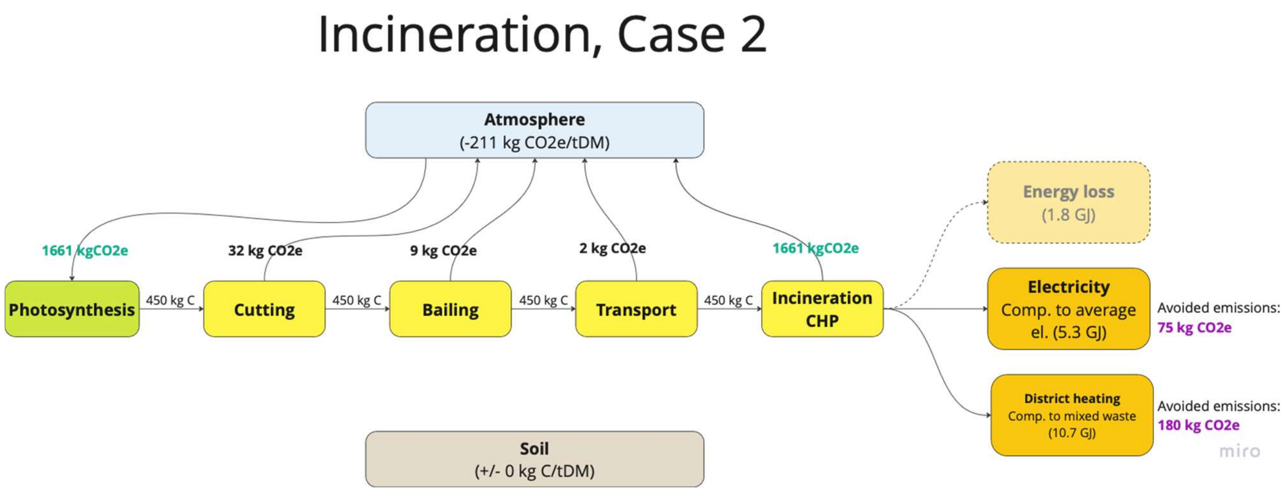

Figure 17. Harvest and treatment in a CHP plant, with electricity produced replacing an average Swedish electricity mix.

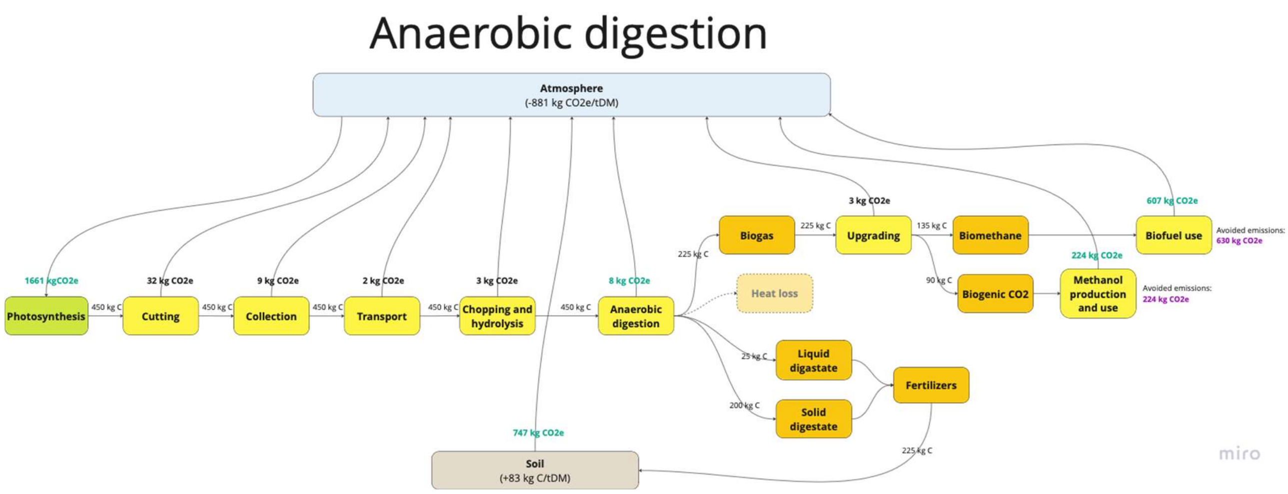

Figure 18. Harvest, anaerobic digestion, and biogas upgrading.

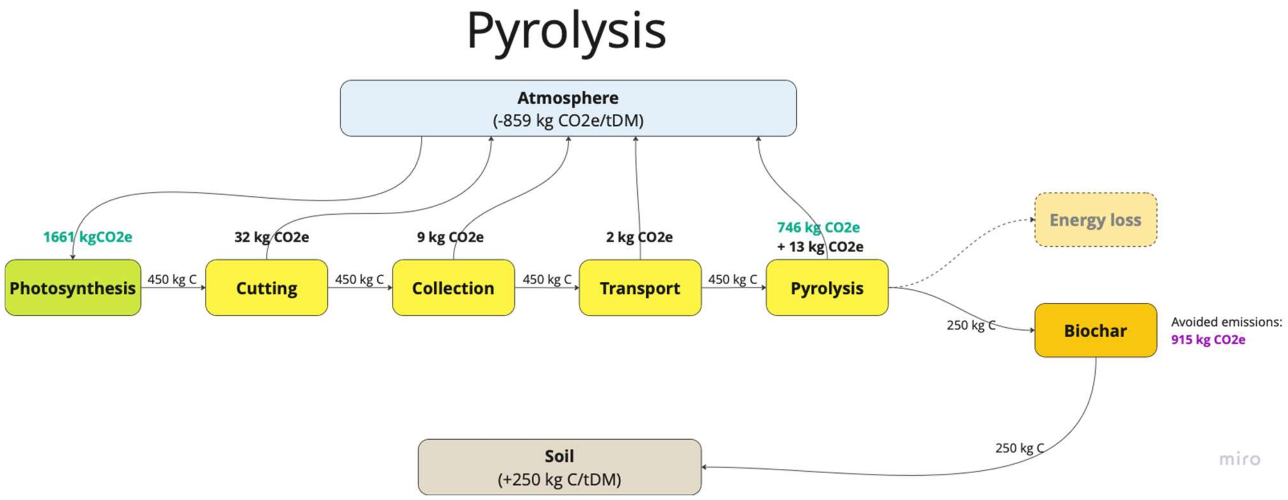

Figure 19. Harvest and pyrolysis in a stand-alone process without energy recovery.

For climate impact, all scenarios result in reduced emissions. Generally, mowing, collection of harvested biomasses, and transport to a facility, have lower influence on the outcome than the choice of biomass treatment process. The highest benefits for the climate can be achieved by treating the harvested biomass with anerobic digestion or in a small-scale pyrolysis plant. Approximately 0.88 tCO_2e/tDM can be avoided for anaerobic digestion, which is similar to pyrolysis in a small-scale plant with 0.86 tCO_2e avoided emissions per ton dry mass.

For pyrolysis, more CO_2-emissions can be avoided in a small-scale plant with process parameters adopted for high biochar yields, even though the excess energy is lost as heat and not utilized for district heating (as would be possible in a large-scale integrated process). The incineration option, where the electricity produced substitutes an average Swedish electricity mix, is only 77 $kgCO_2$/tDM better than BAU. However, if electricity from natural gas is substituted, almost 300 $kgCO_2e$/tDM more can be avoided.

4.1.3. Sensitivity analysis, climate impact

The sensitivity of the results for climate impact was tested systematically by changing the input parameters and assessing the results in a worst- and best-case scenario. The following parameters were assessed:

- Yield: 2 – 10 tDM/ha/yr.
  The yield may vary based on temperature, local conditions, and crop. A range between 2 and 10 tDM/ha is plausible in Sweden.
- Biomass carbon content: 42 – 47%.
  The carbon content differs between different crops. The range corresponds to approximate carbon content in common reed and reed canary grass.
- Carbon retained in soil: 2 – 16%.
  The carbon retained in soil after 100 years varies between 2 and 16%, which have an effect on emissions from natural decomposition of biomass, and emissions from compost products and digastates.
- Transport distance: 10 – 100 km.
  Transport distances may vary but is assumed to be below 100 km for lake meadow biomass having a low density.
- Biogas potential: 250-300 LCH_4/kgVS.

Different ranges of biogas potential based on approximate variety for common reed, reed canary grass and cattail.

- Production of electricity, incineration: 0 – 32% of HHV.
  During incineration, only recovery of energy in the form of district heating may be possible (if not incinerated in a CHP).
- Utilization of biogenic CO_2 for methanol production: 0 – 27% of carbon in biogas.
  Biogenic carbon from purification of biogas may be reused, or, in the worst-case scenario, be released back to the atmosphere.
- Pyrolysis temperature: 350 – 500ºC.
  The temperature in a small-scale pyrolysis may be set higher than 350ºC to get a more stable biochar out from the process. It was assumed that temperatures above 500ºC is less commonly used in stand-alone plants.

Table 2. Sensitivity analysis - possible ranges in GHG emissions per management technique (kgCO2e/tDM)

Scenario	Best case	Base case	Worst case
2. Compost	- 113	**- 61**	+ 8
3a. Incineration, case 1	- 445	**- 429**	- 137
3b. Incineration, case 2	- 228	**- 211**	- 137
4. Anaerobic digestion	- 941	**- 881**	- 656
5a. Pyrolysis, case 1	- 875	**- 859**	- 530
5b. Pyrolysis, case 2	- 615	**- 599**	- 550

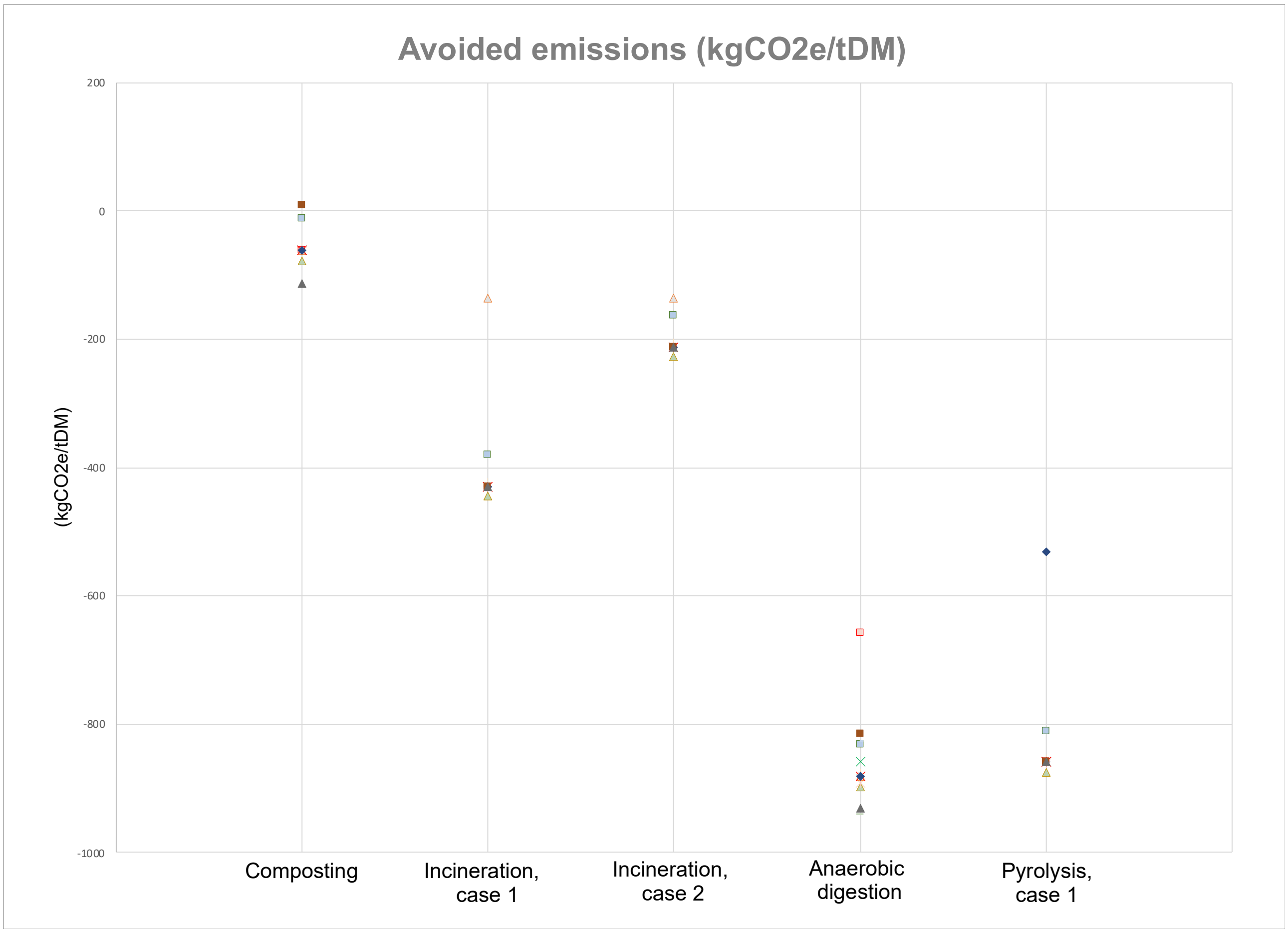

Figure 20. Sensitivity analysis. Avoided GHG emissions for different use of harvested biomass.

The result from the sensitivity analysis shows that all processes to manage harvested biomass leads to a positive climate effect, both in a worst- and a best-case scenario, except for compost which may lead to a minor increase in GHG emissions in a worst-case scenario. The parameters having the largest effects on climate impact is when incineration do no longer replace electricity produced from natural gas (case 1), when the temperature in a small-scale pyrolysis plant is increased to 500°C which results in lower carbon yields, and when the biogenic CO_2 from purification is released instead of used for replacing fossil CO_2.

Differences in yield have small effects on the total climate impact per ton DM. If the yield is 10 tDM/ha, mowing/cutting will emit 16 kgCO_2e/tDM. If the yield is 2 tDM/ha, 81 kgCO_2e/tDM will be emitted from cutting machines. None of the other processes are affected. However, the potential climate benefits per hectare will have large effects. Also transport distance has small effects per ton DM, compared to the chosen waste management method. Increasing the distance to 100 km only leads to 4 kg more CO_2e emitted per tDM.

4.2. Biodiversity

4.2.1. Impact assessment based on literature review

4.2.1.1. Mowing (BAU)

Mowing in the blue border is beneficial for waders and other birds thriving in the zone between water and land. Mowing is furthermore good for seed germination, but the reed grows back to same extent next year if the lake meadow is not maintained continuously. The area cut during mowing can be adopted, hence both clear cutting, aquatic restoration, and creation of mosaic pattern in the lake is possible. When the reed is not removed through grazing or harvest, the plants wither and becomes litter on the lake bottom and in the meadow, and consequently the ground level in the lake slowly raises creating larger meadows and less open water area (Lennartsson & Westin, 2019a). In the long-term perspective, this is assumed to have negative effects on birds, since the open water area will slowly decrease.

4.2.1.2. Harvest

Harvest has to some degree the same impact to biodiversity as mowing, including creation of a blue border which is positive for birds. A large difference is however that the cut reed is removed from the site after mowing. Removing the litter from the lake meadow benefits other vegetation as the meadows are cleared and allows other plants to grow. A large proportion of nutrients is also removed from site during harvest, which would otherwise be added to the soil and water compartment as the plants decompose. Since overgrowth of reed is mainly a problem in eutrophic lakes, nutrient removal through harvest could potentially help to restore lakes to previous state and benefit flora and fauna growing and living in the area as when the meadows were maintained.

4.2.1.3. Grazing

Animal grazing leads to an open area where the vegetation is kept low, which is beneficial for a more diverse flora and in consequence likely also beneficial for insects. Animal trampling can on the other hand cause harm to bird eggs during nesting, hence, have a negative effect on birds' reproduction. Fences can however be placed to create a mosaic pattern around the lake, leaving shares of reed beds standing for nesting.

4.2.2. Impact assessment based on flora and fauna in the region

In the region of Västra Götaland (mainly belonging to the boreal zone), natural eutrophic, oligo-mesotrophic and oligotrophic lakes were identified to have the highest risk for regrowth. The correlation between threatened species in these habitats, and the regrowth and maintenance of lake meadows is presented in Table 3. All species which have not been identified to be directly affected by the maintenance of lake meadows are excluded from the list. Typical and characteristic flora and fauna categorized as being of low concern are also excluded.

Table 3. Species categorized as red-listed according to IUCN or included in Artskyddsförordningen.

Species	Search 1	Search 2	Category	Connection to regrowth in lake meadows, and to different management methods
Birds				
Acrocephalus arundinaceus, Great reed warbler	X		NT	Thrives in mosaic patterned vegetation around lakes, where dense reed beds are alternated with low grass vegetation.
Actitis hypoleucos, Common sandpiper	X	X	NT	Declining in population is not fully set, however is supposed to be connected to the re-growth of lake meadows.
Aythya ferina, Common pochard	X		EN, S	Decrease of aquatic vegetation and decrease of aquatic insects could be a reason since it in turn leads to less feed available for the Common pochard
Chlidonias niger, Black tern	X		VU, S	The regrowth of these small and shallow water streams is one reason for the species' decline.
Larus ridibundus, Black headed gull	X		NT	Lack of nesting places caused by decreased management around lakes threatens the species.
Limosa limosa		X	EN	Bird which needs open area, mosaic pattern, and is dependent on the blue border.
Numenius arquata		X	EN	Requires open area to thrive.
Porzana porzana		X	VU	Requires reed growth but is benefited when reed grows in a mosaic pattern.
Spatula clypeata		X	NT	Bird which benefits by grazing. However, this is not a requirement, and the species can also thrive in overgrown lakes as long as they have access to open shallow water.
Spatula querquedula, Garganey	X	X	EN, S	Decreased mowing and grazing around the natural eutrophic lakes is the main reason for the decreasing population, as the species prefers short grass vegetation prior to high growing reed.
Tachybaptus ruficollis, Little grebe	X		NT	The bird mainly nests in small, naturally eutrophic, lakes with shallow fish-free waters and dense vegetation, such as for instance reed, as well as free vegetation around the lake.
Bryophyte				
Bryum knowltonii		X	EN	May be positively affected by mowing, needs exposed areas.
Dicranella humilis		X	NT	Possibly affected by regrowth in lakes since the species is easily outcompeted by other plants and need managed, exposed or disturbed environment.
Fossombronia incurva		X	VU	Weakly competitive species which need continuous disturbances.
Physcomitrella patens		X	NT	Benefited by grazing.
Riccia huebeneriana		X	EN	Lives in grazed areas, and where birds nest.
Insects				
Agonopterix yeatiana		X	NT	Affected by wetlands degradation in general.
Anthicus sellatus		X	NT	Requires vegetation poor lake meadows.
Baetis liebenauae		X	NT	Positively affected by dense vegetation
Bagous czwalinai		X	NT	Possibly affected positively by maintenance, need buttercup in order to survive.
Bembidion stephensii		X	NT	Possibly affected positively by maintenance, need open area.
Bledius longulus		X	NT	Possibly affected, thrive in vegetation poor flora, with sparce grass growth.
Brachycercus harrisella		X	VU	May be positively affected by high growing reed.
Chaetocnema aerosa		X	NT	Live in open lake meadows and benefit by grazing.
Chlaenius nigricornis		X	NT	Live in open lake meadows and benefit by grazing.

Dibolia occultans		X	NT	Possibly affected positively by maintenance, need open area.
Ischnopoda scitula		X	VU	Possibly affected positively by maintenance, need vegetation poor area.
Nanophyes globulus		X	VU	Live in open lake meadows and benefit by grazing.
Nebria livida		X	VU	Possibly affected positively by maintenance, need vegetation poor area.
Nemoura dubitans		X	VU	Benefited by reed and dense vegetation.
Philonthus rubripennis		X	VU	May be benefited by mowing, live in reed litter.
Vascular plants				
Blysmus compressus		X	VU	Positively affected by grazing.
Cardamine parviflora		X	VU	Outcompeted by dominating plants such as reed.
Carex hostiana		X	NT	Positively affected by grazing.
Cyperus fuscus		X	CR	Grow in open lake meadows.
Deschampsia setacea		X	VU	Benefited from trampling and grazing.
Elatine hexandra	X	X	VU	The vulnerability status of the plant is connected to eutrophication, acidification and exploitation in connection to lake meadows. Grazing is considered a priority to sustain the species.
Elatine orthosperma	X		NT	The risk of the species to be extinct is closely connected to the ceased use of lake meadows, but also eutrophication, and water regulation in lakes. The plant requires either natural regulation in water levels in combination with large differences in temperature between summer and winter, or to be exposed to grazing and trampling in order to survive.
Gentiana pneumonanthe		X	EN	Requires disturbance through maintenance, grazing or ice shearing.
Isolepis setacea	X		EN	It is strongly threatened due to ceased management of lake meadows since reed and other high growing vegetation easily outcompetes this low growing sensitive species
Jacobaea aquatica		X	VU	Grows in grazed lake meadows.
Jacobaea paludosa		X	VU	Grow in areas where grazing has previously been used for maintenance of land.
Juncus foliosus		X	VU	Benefited by trampling.
Leersia oryzoides		X	VU	Exposed to competition by common reed.
Lycopodiella inundata		X	NT	Outcompeted by reed, benefited by grazing.
Persicaria foliosa		X	NT	Outcompeted by reed and high growing vegetation. Benefited by trampling to a certian degree, to high trampling may harm seeds and have negative effect.
Pilularia globulifera	X		VU	Threatened by the regrowth in lakes and requires grazing to thrive and once again establish in more locations
Radiola linoides		X	NT	Likely affected by regrowth, requires scarce growth in lake meadows and easily outcompeted by more dominating plants.
Rorippa amphibia		X	NT	Exposed to competition by reed.
Sagittaria sagittifolia		X	NT	Possibly benefited by non-maintenance. Thrives in eutropic lakes.
Salix daphnoides		X	VU	Possibly affected, easily outcompeted by other vegetation.
Tephroseris palustris		X	CR	Benefited by heavy trampling and open beaches.
Viola stagnina		X	VU	Grow in maintained lake meadows, or meadows exposed to natural ice shearing and water regulations.

Search 1 = occurrence of species in natural eutrophic, oligo-mesotrophic and oligotrophic lakes.
Search 2 = species identified through Artfakta.se.
Category = IUCN red-list (NT, EN, VU, CR) or Artskyddsförordningen (S).
The assessment shows that both flora and fauna are affected by the regrowth in lake meadows, and with several red-listed species being directly affected by maintenance of lake meadows. In total, 11 birds, 5 bryophytes, 15 insects and 22 vascular plants which are threatened could be connected to regrowth in lake meadows within the assessed region.

The first search included vascular plants, bryophyte, birds, fish and cray fish. Out of 51 typical and characteristic species of vegetation growing in lakes, 7 birds and 4 vascular plants were classified as threatened and where regrowth of lake meadows occurs to be one of the main reasons.

The second search included vascular plants, bryophyte, birds, fish, crayfish, mammals, insects, lichens, mollusks. 104 red-listed species were identified in total, whereof 99 species were not identified through search 1. Out of the 99 threatened species, 42 could directly be connected to regrowth and maintenance of lake meadows.

4.2.3. Synthesized impact on biodiversity

The assessment of biodiversity show that all management of lake meadows tend to be positive for a diverse flora and fauna. The vegetation causing regrowth often has invasive characteristics and easily outcompete more low-growing and sensitive vegetation. When monocultures appear, the habitat and diversity around the lake consequently changes affecting insects, birds, and other animals. The most positive effects for biodiversity can be expected when using cattle for grazing, since this leads to an open area where vegetation is continuously kept low, natural creation of a mosaic pattern around the lake, and since the trampling itself in many cases is necessary for seeds to grow. The trampling can however not be too heavy and lead to land degradation since this can instead harm new plants and seeds. Furthermore, cattle must be prevented from reaching some parts of the lake with reed stands, since the trampling can also cause harm to bird eggs.

Harvest of lake meadow biomass has a slightly better effect compared to only mowing since the vegetation is removed from the site and not allowed to decompose. The benefits for flora and fauna are however heavily affected by the choices made for these two scenarios, for example choosing clear-cutting or creating a mosaic pattern in the landscape. A mosaic pattern, with a combination of reed stands, open water and a blue border, is the most optimal environment for birds to revisit a lake. Occurrence of birds is often also seen as an appropriate indicator to determine the state of a wetland in general, since they have the possibility to choose another location in case of bad status of the current wetland (Suter, 1994), for example due to less food (insects and/or fish) or changed habitat.

Insects tend to benefit by management of lake meadows, even though the correlation is less certain in this case. A few insects gain by dense vegetation, but in general, red-listed butterflies, beetles and other insects requires open area and more diverse flora, and hence all maintenance is likely overall positive for threatened species.

Error! Reference source not found. shows the impact on biodiversity of different management techniques based on its effect on flora and fauna.

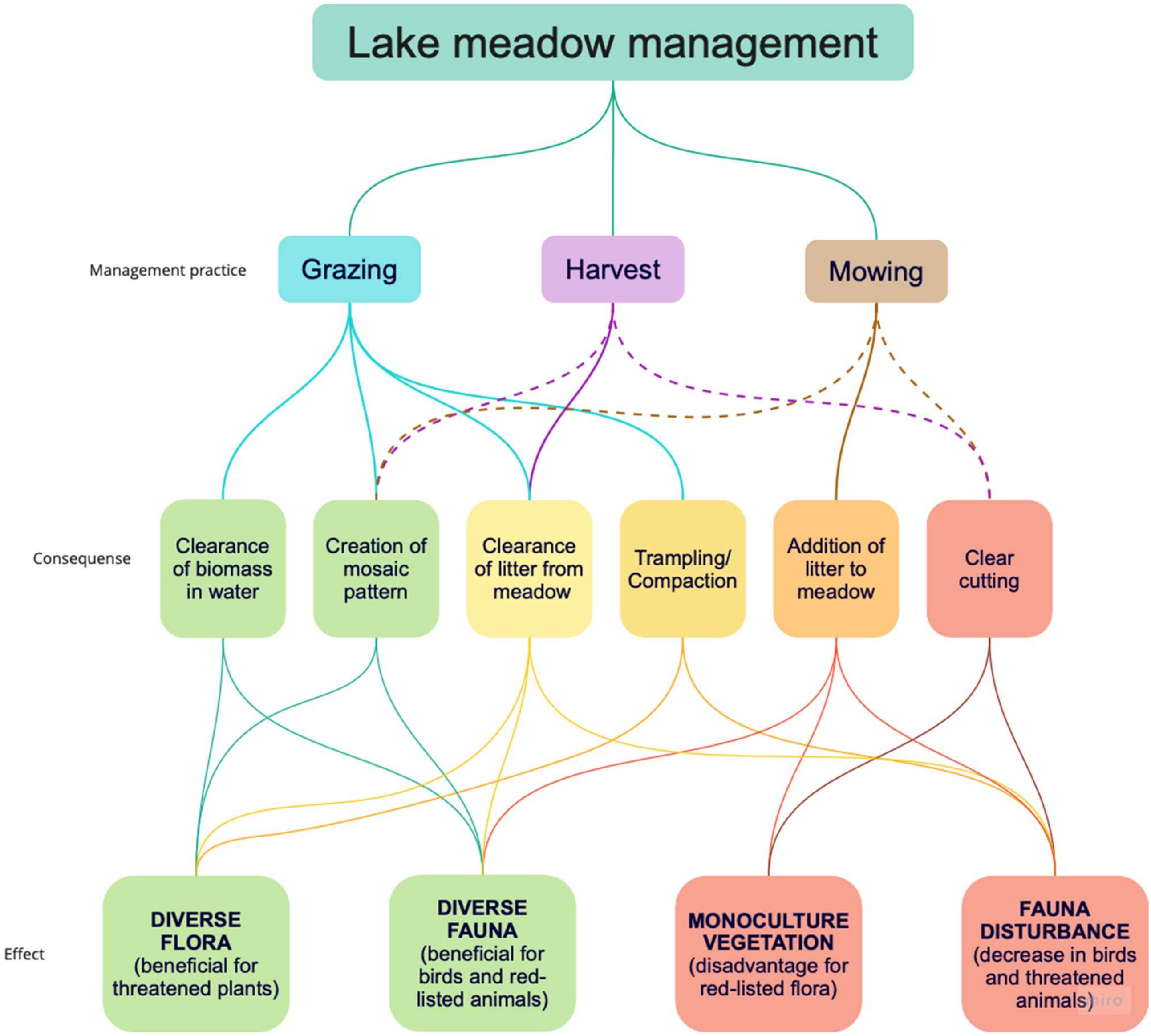

Figure 21. Impact on biodiversity based on different management techniques.

4.3. Feasibility

The possibility to harvest lake meadow grass and utilize the biomass depends on the feasibility in a real-life scenario, including the profitability for individual landowners, legal and societal barriers and existence of infrastructure for managing the harvested biomass.

4.3.1. Scalability

The scalability and the potential benefits for the climate in case of harvesting lake meadows in the whole region of Västra Götaland was identified as very uncertain. The total lake shoreline, average reed bed widths and shares of lakes exposed to regrowth in the region is unknown to a high extent. Furthermore, the accessibility of trucks and cutting machines to lakes is unknown. Therefore, four different circumstances are presented. The potential benefits for the climate, in case of upscaling, is calculated based on a yield of 5 tDM/ha and year and presented for mowing (BAU) and management through harvest and anaerobic digestion.

Table 4. Potential areas to harvest in the region of Västra Götaland and the effects for climate for two scenarios.

Lake meadow width (m)	Share of lakes exposed to regrowth (%)	Potential area to be harvested (ha)	Avoided GHG emission (kiloton CO_2e/year)	
			Mowing (BAU)	Anaerobic digestion
10	10	520	0.3	2.3
10	50	2 600	1.7	11
100	10	5 200	3.5	23
100	50	15 600	10	69
Reference, lake meadows maintained to some extent today		2 000	1.3	9

As a comparison, the total emissions of greenhouse gas emissions in the region of Västra Götaland was in 2020 approximately 8 900 kiloton CO_2e. The emissions from private heating of houses and premises were 127 kiloton CO_2e (Naturvårdsverket, n.d.-b). With the highest estimation of potential area to harvest, approximately 50% GHG emissions can be avoided when using harvested biomass for biogas production compared to the emissions released from private heating.

4.3.2. Profitability

Restoring and managing lake meadows is a complex, cost sensitive and time-consuming project. Primarily these types of projects are heavily dependent on personal engagement from landowners. The costs for harvesting of biomass from regrown lakes differs based on location, type of vegetation and transport distance. Quality of the harvested biomass is also an important factor setting the economic feasibility for the biomass as energy source. In this thesis all these parameters have been considered by mean values. Fundings are based on land area and hectare.

For mowing (BAU), cutting and leaving the biomass on site is done annually, with the costs recurring during the restoration project and during the continuous management. When grazing is applied, this requires a one-time cutting and collecting of biomass prior to the animals continuing grazing. The cost for cutting and collecting biomass is therefore a one-time cost, however the income from leasing the land to animal owners for grazing is annual. Any potential fundings from this management practice will however be paid to the animal owner. For the remaining three management practices, cutting and removing the biomass for various processes is done annually, with the costs and incomes recurring during the restoration project and during the continuous management.

By looking at the costs from a two-sided perspective, both the landowners and the biomass management production processes, the meeting point can be found where business is potentially possible. The production processes, managing harvested lake meadow biomass, has operational costs that shall be covered by the selling of the end-product produced at the facility. This difference is their willingness to pay for the raw material to reach break-even in their production process. Comparing this price with the landowners' costs shows where profitability is found for both parties, hence where the business possibility lies.

4.3.2.1. Harvest by contractor

Table 5 presents the balance of costs and incomes for the different management techniques with the scenario of using a contractor to perform cutting and collection of lake meadow biomass.

The results show that none of the scenarios are fully financed, even if restoration funding is paid to the landowner. Using a contractor for cutting and collecting biomass hence requires the biomass to be sold for this scenario to potentially be profitable.

Table 5. Break-even balance with scenario of using contractor for cutting and collection (SEK/ha).

Scenario using contractor	**Needed income from biomass sales or land leasing to reach break-even, *without* restoration funding**	**Needed income from biomass sales to reach break-even, *with* restoration funding**
BAU - Cutting and left on site	10 000	6 400
Grazing	20 155	20 155
Cutting and collecting biomass for further treatment /selling	20 155	16 555

4.3.2.2. Harvest by landowner

Table 6 presents the balance of costs and incomes for the different management techniques with the scenario of the landowner themselves cutting and collecting the biomass.

The results show that with restoration funding all scenarios, except grazing, reach break-even and covers the landowners' costs of cutting and collection the biomass. Selling biomass will in these cases be a profit for the landowners. Grazing shows that leasing the land to an animal owner for grazing is not a profitable solution for the landowner, as the cost for cutting and clearing is not compensated by the land leasing income since the funding is paid to the animal owner. By selling the biomass for further end processes, grazing could potentially also be profitable.

Table 6. Break-even balance with scenario of the landowner managing the cutting and collection (SEK/ha).

Scenario landowner management	**Needed income from biomass sales or land leasing to reach break-even, *without* restoration funding**	**Needed income from biomass sales to reach break-even, *with* restoration funding**
BAU - Cutting and left on site	1 225	0
Grazing	1 964	1 964
Cutting and collecting biomass for further treatment /selling	1 964	0

4.3.2.3. *Willingness to pay*

Table 7 presents balance of operational costs and incomes from end-product sales for the different management techniques.

The results show that there is a potential willingness to pay for all scenarios. The highest price could be paid for biomass sold to anaerobic process, followed by incineration. Composting pays the lowest price for the sold biomass.

Table 7. Break-even balance for processes handling harvested biomass (SEK/ha)

Production process for managing harvested biomass	Operational cost	Income end-product sales	Willingness to pay
Composting	638	4 128	3 490
Incineration	1 157	18 118	16 961
Anaerobic process	8 434	28 711	20 278
Pyrolysis process	8 923	18 177	9 254

4.3.2.4. *Break-even*

Error! Reference source not found. present the intersections where industry price for raw material cover landowners management costs, making buying and selling profitable for both parties.

When the landowner manages cutting and collecting without contractor, all scenarios, except grazing, are profitable with funding leading to all end-products selling prices, in these cases, being a profit to the landowner. Selling to anaerobic process, however, leads to the highest financial benefit. In the other case where the biomass is cut and collected by a contractor, selling to an anaerobic process is the only case covering the costs of all potential scenarios.

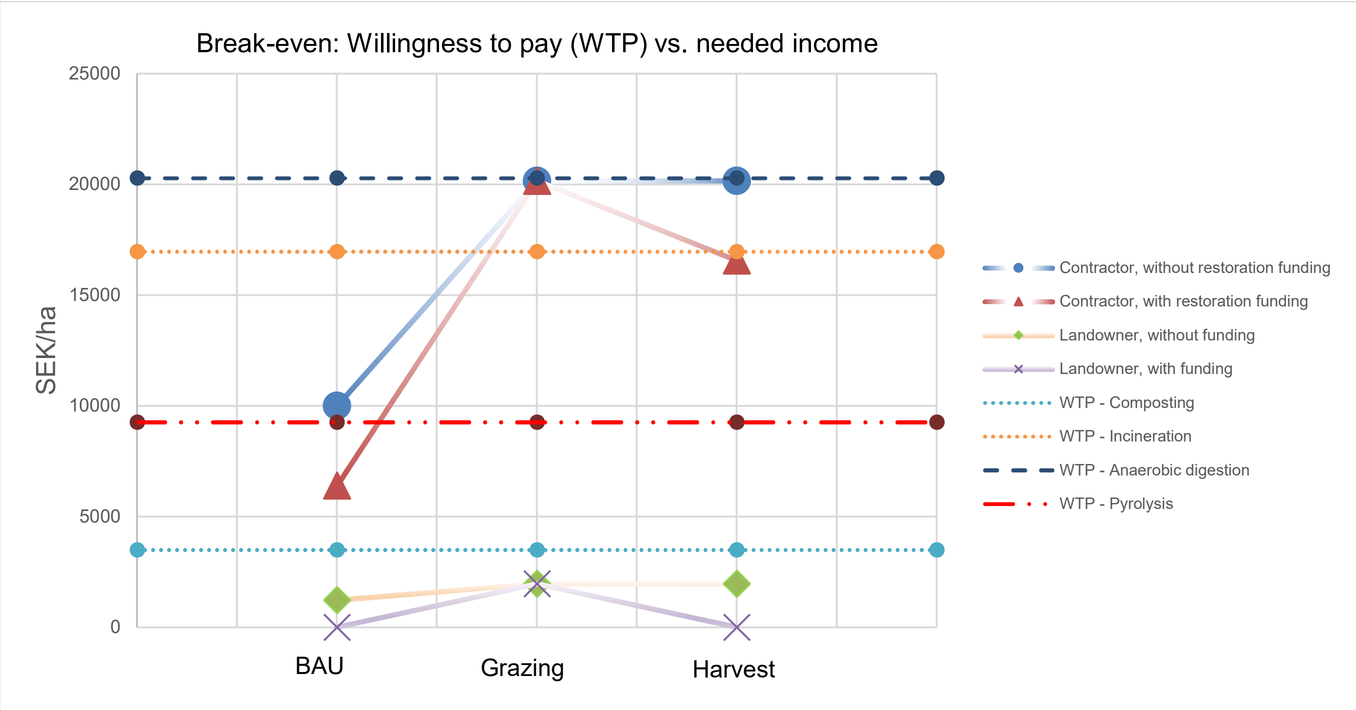

Figure 22. Willingness to pay (WTP) vs. needed income from biomass sales or land leasing.

4.3.3 Financial barriers

For the restoration and management to be scaled up and have a bigger impact, the landowners need to receive compensation, for instance, in the form of funding or selling the biomass covering the expenses and the work performed. It is found that the restoration and management of lake meadows is not profitable unless funding is paid, or the biomass is sold for further end-use. However, the system for applying for funding is currently complex and has a lot of uncertainties for the landowners, where they can receive too little funding, but also be responsible to pay back the funding if project is not approved by the agencies during the final audit. These uncertainties and risks lead to many landowners being hesitant to apply for the current fundings, hence leaving the land unmanaged.

Funding is a possible income for private landowners and municipalities who would like to restore and maintain lake meadows. However, there are some direct drawbacks.

- Most funding covers the restoration of lake meadows or selective measures, and further fundings need to be applied for in order to cover the continuous management needed to prevent regrowth.
- One grant is available for maintenance for private landowners, but this only covers 40% of the estimated costs connected to lake meadow biomass harvest. Another income is therefore needed to create incitements for landowners to perform continuous harvest.
- Audits on site is performed by the County Administrative Board or the Swedish Board of Agriculture to verify and control that the application corresponds to the actual preconditions and implement of the plan in the lake, and repayment is demanded if any faults are found. The risk for landowners to be liable for reimbursement is sometimes a barrier for them even to apply (Fredriksson, 2023).
- The support from the Swedish Board of Agriculture, including the funding available for maintenance, is possible to apply for during 2023-2027. It may however be lowered if available capital runs out earlier (*Jordbruksverket*, n.d.-b), and it is not certain that a corresponding support will be available after this period.

4.3.4. Societal barriers

Personal interest and engagement in restoring and managing regrown lake meadows is a major barrier. There are also further barriers identified. Interaction with agencies such as the County Administrative Board and the Swedish Board of Agriculture can be complicated, where the risk is that landowners skip initiating a project merely due to that they are lost in bureaucracy. It is important that the interaction with the agencies works well, for the landowner to receive support during the funding application process, in the start-up phase as well as during the project and in the final audit.

The procedure to apply for and receive funding is complex and bureaucratic, with several barriers linked to it. The area of restoration needs to be specified at an early stage, where the buoyancy of land might be unknown, hence the possibility to restore land needs to be very roughly estimated. This is a barrier as estimating too small an area leads to not receiving costs in relation to your expenses, and overestimation can lead to the landowner becoming liable for repayment if the project is not in line with application.

The application period runs from five years; however, landowner commits to a 10-year management period, leading to a long commitment time for the landowners.

Having animals grazing the land works well for restoration of overgrown lake meadows, however requires the landowner to have animals and the possibility and engagement to put into all the work needed. Grazing animals in these lake meadows requires moving the animals frequently for even grazing, moving fences as the water level fluctuates (since virtual fences are yet not allowed in Sweden), as well as putting the animals at risk of drowning. On the other hand, using machines to restore and manage the lake meadows requires special machines, specifically when the buoyancy is low, rarely found at any landowner. In these cases, an external contractor could be used to manage the land, which in all cases leads to high costs linked to the restoration and management.

Barriers can also be found related to lack of time and interest from landowners, as well as more old-fashioned thinking where nature has its own course, which is not always beneficial for the land. At a higher level, there are also barriers linked to continuity of regulations and authorities as government and governmental strategies and subventions change. (Bäckström, 2023; Bertilsson, 2023; Eriksson, 2023; Fredriksson, 2023; Pederson, 2023). For the lakes in Västra Götaland to be restored and continuously be managed, they require dedicated landowners understanding and valuing the positive climate impact and benefit for biodiversity, thus accepting the cost and workload involved.

4.3.5. Technical barriers

Technical barriers are found in almost all stages of the process with managing lake meadows. Primarily, there are challenges linked to the availability of correct equipment for harvesting biomass. Traditional tractors and machines found at common landowners, can cut and collect when the bearing capacity of the soil is good, however working close to the water requires special machinery. This would in most cases require a contractor to be used for performing the work, leading to another barrier. As most of the harvesting in Västra Götaland needs to be performed during certain periods of the year, and the skilled contractors within this field are few, one can assume that the availability of contractors is also limited. As the lake meadows sometimes are remotely located, accessibility for trucks and special machinery can also be a barrier (Bertilsson, 2023; Eriksson, 2023; Linding, 2023).

As lake meadow biomass, primary reed, is bulky, the transportation distance to any potential further process is of importance. There are limited possibilities for processing the biomass within Västra Götaland which further challenges the feasibility. The processes available within the region are also a barrier, as the acceptance of lake meadow biomass as biomass feedstock at municipal waste treatment plants and pyrolysis plants are low.

A possibility to increase the feasibility is if the availability of small-scale pyrolysis plants increases and therefore eases for the landowner through reduced transportation as well as the contact with the industry.

Other parameters hindering the feasibility are the limited availability to accurate machines that work well in wetlands, but also the overall challenges of restoring and maintaining these wetlands with low buoyancy.

4.3.6. Grazing barriers

Grazing the land is seen to have the most positive effect for biodiversity, however there is a direct drawback and risk when increasing grazing in lake meadows because of the possible parasite the Common liver fluke. The infection is often first detected at slaughter of the animal, making the meat partly or fully unusable, depending on spread of the parasite (Livsmedelsverket, n.d.; Statens Veterinärmedicinska Anstalt, n.d.; Novobilsky et al., 2012; Pettersson, 2023). This is a large risk for the animal owner, that could result in zero income from meat production. The infection could also cause abdominal pain and sudden death which leads to the question if the risk is ethical or not to take.

The lean pasture around lake meadows can hinder growth of the grazing ruminants. This too is a risk for the animal owner, as it could decrease or fully remove the profitability of using grazing ruminants, bred for meat production, for lake meadow restoration and management (Pettersson, 2023). The cattle must furthermore be moved between different areas continuously to prevent land degradation by too heavy grazing and trampling, which takes time and costs money.

4.3.3. Sensitivity analysis, profitability

The sensitivity of the results for financial impact based on different management techniques was tested systematically by changing the input parameters and assessing the results in a worst- and best-case scenario. The following parameters were tested:

- Transport distance: 10 – 100 km.
  Transport distances may vary but is assumed to be below 100 km for lake meadow biomass having a low density.
- Contracting cost: 8 – 12 000 SEK/ha.
  The cost is assumed to be 10 000 SEK/ha (average value based on interview with LVR Våtmarksrestaurering) for harvesting and collecting biomass, however, it may vary between 8 000 and 12 000 SEK/ha (possibly even higher), depending on ground buoyancy etc.
- Change in price of biomass sales: +/- 20%.
  The market price for reed as raw material for waste management methods may vary, here estimated to be +/- 20 % of prices collected from literature and interviews.
- Change in price of operational costs: +/- 10%.
  The operational cost for different management techniques of harvested reed may vary, here estimated to be +/- 10 % of costs collected from literature.

Table 8. Break-even balance with scenario of using contractor for cutting and collection, best vs. worst-case scenario (SEK/ha)

Scenario using contractor	**Needed income from biomass sales or land leasing to reach break-even, *without* restoration funding**			**Needed income from biomass sales to reach break-even, *with* restoration funding**		
	Worst case	**Base case**	**Best case**	**Worst case**	**Base case**	**Best case**
BAU - Cutting and left on site	+ 2 000	10 000	- 2 000	+ 2 000	6 400	- 2 000
Grazing	+ 4 131	20 155	- 4 037	+ 4 131	20 155	- 4 037
Cutting and collecting biomass for further treatment /selling	+ 4 131	20 155	- 4 037	+ 4 131	16 555	- 531

Table 9. Financial balance, best vs. worst-case scenario, with landowner managing cutting and collection (SEK/ha)

Scenario using landowner management	**Needed income from biomass sales or land leasing to reach break-even, *without* restoration funding**			**Needed income from biomass sales to reach break-even, *with* restoration funding**		
	Worst case	**Base case**	**Best case**	**Worst case**	**Base case**	**Best case**
BAU - Cutting and left on site	+/- 0	1 225	+/- 0	0	0	0
Grazing	+130	1 964	- 37	+ 130	1 964	- 37
Cutting and collecting biomass for further treatment /selling	+130	1 964	- 37	0	0	0

Table 10. Willingness to pay for processes handling harvested biomass, best vs. worst-case scenario (SEK/ha)

Production process for managing harvested biomass	**Willingness to pay**		
	WORST CASE	**BASE CASE**	**BEST CASE**
Composting	- 889	3 490	+ 890
Incinceration	- 3 739	16 961	+ 3 739
Anaerobic process	- 6 586	20 278	+ 6 586
Pyrolysis process	- 4 527	9 254	+ 4 527

The results from the sensitivity analysis show that when the landowner manages cutting and collecting without using a contractor, the willingness to pay for biomass in all production processes worst-case still covers all the scenarios worst-case costs. However, if the landowner uses a contractor for cutting and collecting biomass the outcome changes, and covering the cost is more challenging. In the willingness to pay worst-case, the only worst-case cost scenario that can be covered is BAU, however in this case no biomass is sold, hence the option is not relevant. In the willingness to pay best-case scenario, anaerobic process is the only production process that can cover all the scenarios worst-case costs, regardless of who cuts and collects the biomass from the meadow.

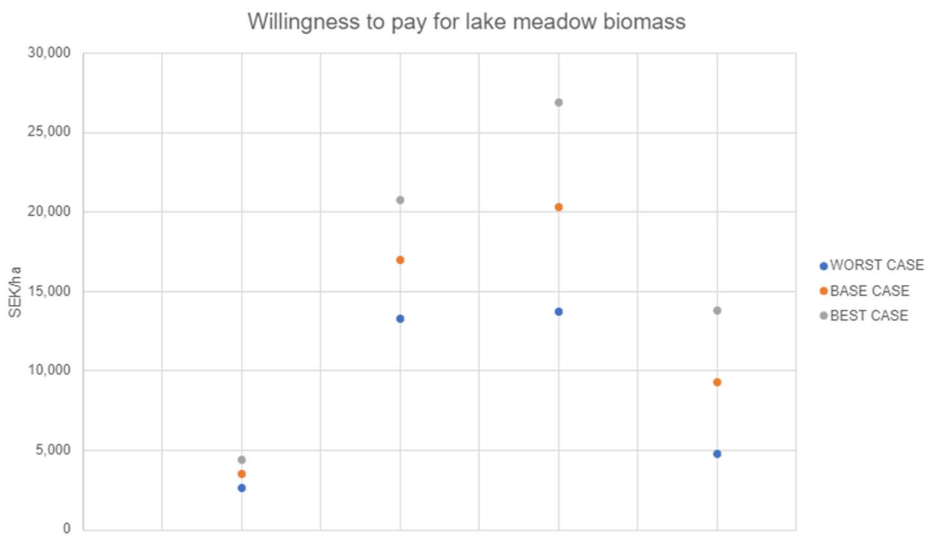

Figure 23. Sensitivity analysis, willingness-to pay for lake meadow biomass (SEK/ha).

5. CONCLUSION

Lake meadows have historically been utilized for its fodder resources, both through grazing and yearly harvest. As the agricultural system became industrialized around the 20^{th} century, the importance of lake meadows as fodder resource however decreased since cheap and nutrient rich fodder could be attained from arable land. The ceased maintenance has led to a regrowth of many lake meadows, affecting the flora and fauna which has earlier been thriving in these areas. Today only a small share of lake meadows is maintained, and then mainly for nature restoration purposes.

Several types of reeds and sedge grow in freshwater lake meadows. To a limit, these high-growing vegetation have benefits for the lake fauna. They provide protection to wildlife such as cover for bird nests, feed for animals, and act as host plants for certain insects. However, species such as common reed and acute sedge have invasive characteristics, and if not controlled, they easily outcompete more sensitive plants and create a dense monoculture vegetation changing the habitat in the lake. Shallow lakes which are open from regrowth are for example a pre-condition for several birds to come back for their yearly nesting.

Regrowth in lake meadows is a natural aging process, but the lakes which mainly poses a risk for regrowth are eutrophic lakes. These can either be naturally eutrophic lakes, or lakes which are eutrophic due to external impact, e.g., nutrient runoff from upstream agricultural land, influence on water levels in the lake, forestry in connection with the lake or point source emissions. Ice-shearing or water fluctuations in the lake is nature's method to limit regrowth, but often maintenance in the form of grazing, mowing or harvest is needed. Harvest of lake meadow biomass can create benefits both for the climate and biodiversity. With an increased demand for biomass to replace fossil alternatives, vegetation such as common reed has the potential to be an alternative biomass resource. Restoration and maintenance of lake meadows also have the possibility to counteract continued decrease in biodiversity.

The most used method today to manage lake meadows is mowing, where the biomass is cut and left on site. If the biomass instead was harvested, i.e., cut, gathered, and removed from the lake, it would be possible to treat the biomass through composting, incineration, anaerobic digestion or in a pyrolysis plant. When assessing the climate impact on a 100-year scale (GWP100), all these waste management options result in avoided emissions compared to BAU (mowing). The highest benefit for the climate is achieved when the harvested biomass is treated through anaerobic digestion, with subsequent biogas upgrading to biofuels, which lead to approximately 0.9 tCO_2e/tDM avoided emissions. If it would be possible to harvest an essential part of the lake meadows in the region of Västra Götaland (50% of the shorelines with less than 100 meters to farmland), and use the biomass for biogas, around 10-70 $ktCO_2e$ could potentially be avoided per year. A similar saving would be possible if the harvested biomass is treated in a pyrolysis plant at 350°C.

For biodiversity, all management of lake meadows tends to be positive for a diverse flora and fauna. The most positive effects for biodiversity can be expected when using cattle for grazing, since this leads to an open area where vegetation is continuously kept low, it creates a natural mosaic pattern around the lake (which is optimal for animals), and since the trampling itself in many cases is necessary for seeds to grow. There are however some major drawbacks with grazing. The cattle must be moved between different areas continuously to prevent land degradation, which takes time and costs money. The meadows provide lean pasture, which reduces the growth of the ruminates and consequently decreases income from slaughter. Furthermore, ruminants grazing around lakes are very exposed to the common liver fluke. All these factors make lake meadows a high-risk, and a low profitability area to keep animals intended for meat production and it is difficult to find animal owners who want to let their animals graze in connection with lakes. Harvest of biomass, the second-best option, may therefore realistically be a better alternative for biodiversity.

There are challenges in harvesting lake meadow biomass along lakes, both from a technical, social and profitability point of view. Landowners have limited time and interest in managing these meadows, as they potentially do not result in any large financial profit but rather in many risks connected to managing the land. Furthermore, the system for funding of restoring and managing lake meadows are complex, limiting landowners to apply and get financial support.

If the landowner performs the mowing and harvest by themselves, break-even is reached with fundings from the Swedish Agricultural Board, and no further income is needed. However, if grazing is used, the funding is assigned to the animal owner which mean that also sales of harvested biomass is needed (which may not be possible since the animals keep the vegetation low and prevent regrowth). If an external contractor is used for harvest of the lake meadow biomass, both funding and sales of biomass is needed to reach break-even. Only anaerobic digestion covers the costs also in a worst-case scenario, making this the most promising alternative from a profitability point of view.

From a technical point of view, there are several barriers that need to be addressed if an upscaling would be possible. Lake meadows generally have low buoyancy and special machines are needed for mowing and harvest. There's a limited availability of these machines, and since harvest will be needed approximately at the same time within the whole region, this will further limit the availability. Furthermore, there's a low interest from waste management companies to accept lake meadow biomass. Today, only biogas facilities appear to receive this type of vegetation for further treatment. CHP plants (incineration) and pyrolysis facilities does currently not accept harvested biomass as a raw material in their processes. There's also a limited availability of pyrolysis facilities in the region.

Overall, harvest of lake meadow biomass and treatment in a biogas facility (anaerobic digestion and upgrading) have the highest potential to create benefits both for biodiversity and the climate, and simultaneously create profit for individual landowners. However, for an upscaling to be possible, the support schemes need to be simplified and entail a lower risk, higher profitability is needed to create incitements for landowners to manage the land, more suitable machines must be available, and the waste management production units must be fitted to use harvested lake meadow biomass as raw material.

6. REFERENCES

Abhijeet, P., Swagathnath, & G., Rangabhashiyam, & S., Rajkumar, & M. A., & Balasubramanian, & P. (n.d.). *Prediction of pyrolytic product composition and yield for various grass biomass feedstocks*. https://doi.org/10.1007/s13399-019-00475-5/Published

Abhijeet, P., Swagathnath, & G., Rangabhashiyam, & S., Rajkumar, & M. A., & Balasubramanian, & P. (2019). Prediction of pyrolytic product composition and yield for various grass biomass feedstocks. *Biomass Conversion and Biorefinery*. https://doi.org/10.1007/s13399-019-00475-5/Published

Agus, F., Hairiah, K., & Mulyani, A. (2011). *Measuring carbon stock in peat soils* (p. 60).

Ahlgren, K. (2001). *Biobränslen i Söderhamn*.

Artdatabanken - Rödlistning. (n.d.). Retrieved March 2, 2023, from https://www.artdatabanken.se/det-har-gor-vi/rodlistning/Sammanfattning-rodlista-2020/

Bäckström, G. (2023, March 29). *Interview land user*.

Bansal, S., Lishawa, S. C., Newman, S., Tangen, B. A., Wilcox, D., Albert, D., Anteau, M. J., Chimney, M. J., Cressey, R. L., DeKeyser, E., Elgersma, K. J., Finkelstein, S. A., Freeland, J., Grosshans, R., Klug, P. E., Larkin, D. J., Lawrence, B. A., Linz, G., Marburger, J., … Windham-Myers, L. (2019). Typha (Cattail) Invasion in North American Wetlands: Biology, Regional Problems, Impacts, Ecosystem Services, and Management. In *Wetlands* (Vol. 39, Issue 4, pp. 645–684). Springer Netherlands. https://doi.org/10.1007/s13157-019-01174-7

Baumann, H., & Tillmann, A.-M. (2004). *The Hitch Hiker's Guide to LCA (Tab App. 1.5)*.

Bertilsson, M. (2023, March 29). *Interview land user*.

Boldrin, A., Andersen, J. K., & Christensen, T. H. (2011). Environmental assessment of garden waste management in the Municipality of Aarhus, Denmark. *Waste Management*, *31*(7), 1560–1569. https://doi.org/10.1016/j.wasman.2011.01.010

Borås Energi och Miljö. (n.d.). *Kraftvärmeverket på Sobacken*. Retrieved March 31, 2023, from https://www.borasem.se/webb/omborasenergiochmiljo/varaanlaggningar/energiochmiljocenter/kraftvarmeverket.4.1544b908169955a8b1a4a05d.html

Bright Renewables. (n.d.). *Biogas upgrading: How does it work?* . Retrieved March 31, 2023, from https://www.bright-renewables.com/upgrading-biogas-to-biomethane-how-does-it-work/

Carnevale, M., Longo, L., Gallucci, F., & Santangelo, E. (n.d.). *Influence of the harvest time and the airflow rate on the characteristics of the Arundo biochar produced in a pilot updraft reactor*. https://doi.org/10.1007/s13399-020-01241-8/Published

Carson, B. D., Lishawa, S. C., Tuchman, N. C., Monks, A. M., Lawrence, B. A., & Albert, D. A. (2018). Harvesting invasive plants to reduce nutrient loads and produce bioenergy: an assessment of Great Lakes coastal wetlands. *Ecosphere*, *9*(6). https://doi.org/10.1002/ecs2.2320

Chen, L., de Haro Marti, M., Moore, A., & Falen, C. (n.d.). *DAIRY COMPOST PRODUCTION AND USE IN IDAHO*. http://www.cias.wisc.edu/wp-content/uploads/2008/07/artofcompost.pdf

Croon, F. W. (2013). *Saving reed lands by giving economic value to reed* (Vol. 13, Issue 14). http://www.mires-and-peat.net/,ISSN1819-754X

Cubars, E., & Noviks, G. (2012). Evaluation of reed resources in Latvia and analysis of its use for energy production. *Journal of Environmental Biology*, *33*, 387–392.

Czekała, W., Jasiński, T., Grzelak, M., Witaszek, K., & Dach, J. (2022). Biogas Plant Operation: Digestate as the Valuable Product. In *Energies* (Vol. 15, Issue 21). MDPI. https://doi.org/10.3390/en15218275

Dagens Nyheter. (2020). *Vattenbufflarna Maud och Ellen släpps ut i Stockholm*. https://www.dn.se/sthlm/vattenbufflarna-maud-och-ellen-slapps-ut-i-stockholm/

de Jong, A. (2009). *Planeringsunderlag för restaurering och anläggning av våtmarker i odlingslandskapet i Västerbottens län*.

Degerman, E., Sverige. Naturvårdsverket., & Sverige. Fiskeriverket. (2008). *Ekologisk restaurering av vattendrag*. Naturvårdsverket.

Demirbas, A. (2011). Waste management, waste resource facilities and waste conversion processes. *Energy Conversion and Management*, *52*(2), 1280–1287. https://doi.org/10.1016/j.enconman.2010.09.025

Drivkraft Sverige. (n.d.). Retrieved April 3, 2023, from https://drivkraftsverige.se/fakta-statistik/priser/

Dubrovskis, V., Adamovičs, A., & Plūme, I. (n.d.). *ENGINEERING FOR RURAL DEVELOPMENT BIOGAS PRODUCTION FROM REED CANARY GRASS AND SILAGE OF MIXED OATS AND BARLEY*.

EC, T. E. P. A. T. C. O. T. E. U. (n.d.). *DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources*. Retrieved April 4, 2023, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

Energigas Sverige. (n.d.). Retrieved May 8, 2023, from https://www.energigas.se/fakta-om-gas/biogas/faq-om-biogas/vad-ar-energiinnehallet-i-naturgas-biogas-och-fordonsgas/

Energimyndigheten. (n.d.). Retrieved May 2, 2023, from https://www.energimyndigheten.se/statistik/energilaget/?currentTab=1

Energimyndigheten. (2021). *Växthusgasutsläpp*. https://www.energimyndigheten.se/fornybart/hallbarhetskriterier/drivmedelslagen/vaxthusgasutslapp/

Eriksson, T. (2023, March 29). *Interview landowner*.

Ermolaev, E. (2015). *Greenhouse gas emissions from food and garden waste composting : effects of management and process conditions*. Department of Energy and Technology, Swedish University of Agricultural Sciences.

EU - förnyelsebar energi. (n.d.). Retrieved April 24, 2023, from https://www.europarl.europa.eu/factsheets/sv/sheet/70/fornybar-energi

Feuerbach, P., Strand, John., & Hushållningssällskapet Halland. (2014). *Praktisk handbok för våtmarksbyggare*. Hushållningssällskapet Halland.

Finish Food Authority. (2017). *Sköt vårdbiotopen systematiskt*. https://rorflenodlarna.se

Flygh, G. (2023, April 3). *Interview Länsstyrelsen*.

Fredriksson, F. (2023, March 30). *Interview Länsstyrelsen*.

Gao, J., Li, J., Wachemo, A. C., Yuan, H., Zuo, X., & Li, X. (2020). Mass conversion pathway during anaerobic digestion of wheat straw. *RSC Advances*, *10*(46), 27720–27727. https://doi.org/10.1039/d0ra02441d

GIZ, D. G. fur I. Z. G. (n.d.). *Biowaste to Biogas*.

Göteborg Energi. (n.d.). *Gemensam klimatsatsning med biokolsanläggning*. Retrieved April 3, 2023, from https://www.goteborgenergi.se/i-var-stad/artikelbank/renova-goteborg-energi-biokolsanlaggning

Göteborgs Energi. (n.d.). Retrieved May 2, 2023, from https://www.goteborgenergi.se/foretag/fjarrvarme/fjarrvarmepriser#energiforbrukning

Granéli, W. (1984). Reed Phragmites australis (Cav.) Trin. ex Steudel as an Energy Source in Sweden. In *Biomass* (Vol. 4).

Grosshans, R., Grieger, L., Ackerman, J., Gauthier, S., Swystun, K., Gass, P., Roy, D., & Org, I. (2014). *Cattail Biomass in a Watershed-Based Bioeconomy: Commercial-scale harvesting and processing for nutrient capture, biocarbon and high-value bioproducts*. www.iisd.org

Günther, A., Huth, V., Jurasinski, G., & Glatzel, S. (2015). The effect of biomass harvesting on greenhouse gas emissions from a rewetted temperate fen. *GCB Bioenergy*, *7*(5), 1092–1106. https://doi.org/10.1111/gcbb.12214

Haeldermans, T., Campion, L., Kuppens, T., Vanreppelen, K., Cuypers, A., & Schreurs, S. (2020). A comparative techno-economic assessment of biochar production from different residue streams using conventional and microwave pyrolysis. *Bioresource Technology*, *318*. https://doi.org/10.1016/j.biortech.2020.124083

Hansson, P. A., & Fredriksson, H. (2004). Use of summer harvested common reed (Phragmites australis) as nutrient source for organic crop production in Sweden. *Agriculture, Ecosystems and Environment*, *102*(3), 365–375. https://doi.org/10.1016/j.agee.2003.08.005

Havlík, J., & Dlouhý, T. (2020). Indirect dryers for biomass drying—comparison of experimental characteristics for drum and rotary configurations. *ChemEngineering*, *4*(1), 1–11. https://doi.org/10.3390/chemengineering4010018

Heinsoo, K., Hein, K., Melts, I., Holm, B., & Ivask, M. (2011). Reed canary grass yield and fuel quality in Estonian farmers' fields. *Biomass and Bioenergy*, *35*(1), 617–625. https://doi.org/10.1016/j.biombioe.2010.10.022

Hetz, E., & Sonesson, U. (1993). *Energy analysis of reed canary grass for solid fuel and ley for biogas*. https://pub.epsilon.slu.se/3871/1/175_Hetz%2C_Sonesson.pdf

Hultberg, M., Prade, T., Bodin, H., Vidakovic, A., & Asp, H. (2018a). Adding benefit to wetlands – Valorization of harvested common reed through mushroom production. *Science of the Total Environment*, *637–638*, 1395–1399. https://doi.org/10.1016/j.scitotenv.2018.05.106

Hultberg, M., Prade, T., Bodin, H., Vidakovic, A., & Asp, H. (2018b). Adding benefit to wetlands – Valorization of harvested common reed through mushroom production. *Science of the Total Environment*, *637–638*, 1395–1399. https://doi.org/10.1016/j.scitotenv.2018.05.106

Hultengren, S., & Karlsson, L. (2018). *Naturvårdsprogram för Åmåls kommun*. https://www.amal.se/media/468377/amal-naturvardsprogram-senaste-20181129_2.pdf

IEA. (n.d.). *An introduction to biogas and biomethane*. Retrieved March 31, 2023, from https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane

Jansson, T. (2013). *Riskbedömning för spridning av signalkräftor från Vänern i tillflöden i norra Dalsland*.

Joint Research Center. (n.d.). *Greenhouse gas emissions from fossil fuel fired power generation systems*. http://www.jrc.nl

Jordbruksverket. (n.d.-a). *Investeringsstöd för biogas*. Retrieved April 4, 2023, from https://jordbruksverket.se/stod/fornybar-energi/investeringsstod-for-biogas

Jordbruksverket. (n.d.-b). Retrieved March 20, 2023, from https://jordbruksverket.se/stod/jordbruk-tradgard-och-rennaring/vatmarker-vattenvard-kalkfilterdiken-och-bevattningsdammar/skotsel-av-vatmarker-och-dammar

Jordbruksverket. (n.d.-c). *Miljöersättning för skötsel av våtmarker och dammar 2023*. Retrieved April 4, 2023, from https://jordbruksverket.se/stod/jordbruk-tradgard-och-rennaring/vatmarker-vattenvard-kalkfilterdiken-och-bevattningsdammar/skotsel-av-vatmarker-och-dammar

Köbbing, J. F., Thevs, N., & Zerbe, S. (2013). *The utilisation of reed (Phragmites australis): a review* (Vol. 13, Issue 14). http://www.mires-and-peat.net/,

Köbbing, J. F., & Zerbe, S. (2013). *The utilisation of Reed (Phragmites australis)-a review Article in Mires and Peat · October 2013 CITATIONS 153 READS 6,334*. http://www.mires-and-peat.net/, Komulainen, Martti., Simi, P., Hagelberg, Eija., Ikonen, Iiro., Lyytinen, Sami., Salmela, Pia., & Saarijärven Offset. (2008a). *Reed energy possibilities of using the Common Reed for energy generation in Southern Finland*. Turku University of Applied Sciences.

Komulainen, Martti., Simi, P., Hagelberg, Eija., Ikonen, Iiro., Lyytinen, Sami., Salmela, Pia., & Saarijärven Offset. (2008b). *Reed energy possibilities of using the Common Reed for energy generation in Southern Finland*. Turku University of Applied Sciences.

Lagerkvist, N. (2004). *Kvalitetskriterier för våtmarker i odlingslandskapet - kriterier för rening av växtnäring med beaktande av biologisk mångfald och kulturmiljö*.

Länsstyrelsen. (n.d.-a). *Lokala naturvårdssatsningen (LONA)*. Retrieved April 4, 2023, from https://www.lansstyrelsen.se/vastra-gotaland/natur-och-landsbygd/stod-till-naturvard/lokala-naturvardssatsningen-lona.html

Länsstyrelsen. (n.d.-b). *Lokala vattenvårdsprojekt (LOVA)*. Retrieved April 4, 2023, from https://www.lansstyrelsen.se/vastra-gotaland/miljo-och-vatten/atgarder-och-verksamheter-i-vatten/stod-for-atgarder-i-vatten/lokala-vattenvardsprojekt-lova.html

Länsstyrelsen. (n.d.-c). *VISS, Vatteninformationssystem i Sverige, Tydjesjön*. Retrieved January 26, 2023, from https://viss.lansstyrelsen.se/Waters.aspx?waterMSCD=WA91721096

Länsstyrelsen Stockholm. (n.d.). Retrieved February 13, 2023, from https://www.lansstyrelsen.se/stockholm/besoksmal/naturreservat/fysingen.html?sv.target=12.382c024b1800285d5863a89d&sv.12.382c024b1800285d5863a89d.route=/&searchString=&counties=&municipalities=&reserveTypes=&natureTypes=&accessibility=&facilities=&sort=none

Länsstyrelsen Västra Götaland. (2022, May 5). *Jordbiten*. www.atransvattenrad.se

Länsstyrelsen Västra Götaland, & Skogsstyrelsen. (n.d.). *NATURBRUKSPLAN SAMVERKAN FÖR HELHETSLÖSNINGAR*.

Länsstyrelsen Västra Götalands Län. (2021). *Lodning och djupkartor för sjöar i Västra Götalands län 2021*.

Lennartsson, T., & Westin, A. (2019a). *ÄNGAR OCH SLÅTTER*.

Lennartsson, T., & Westin, A. (2019b). *ÄNGAR OCH SLÅTTER - Historia, ekologi, natur- och kulturmiljövård*.

Linding, A. (2023, February 20). *Interview LVR våtmarksrestaurering AB*.

Liu, F., Zhang, Y., Liang, H., & Gao, D. (2019). Long-term harvesting of reeds affects greenhouse gas emissions and microbial functional genes in alkaline wetlands. *Water Research*, *164*. https://doi.org/10.1016/j.watres.2019.114936

Livsmedelsverket - stora leverflundran. (n.d.). Retrieved April 24, 2023, from https://kontrollwiki.livsmedelsverket.se/artikel/639/c-etiologisk-indelning#Stora_leverflundran

Lizasoain, J., Rincón, M., Theuretzbacher, F., Enguídanos, R., Nielsen, P. J., Potthast, A., Zweckmair, T., Gronauer, A., & Bauer, A. (2016). Biogas production from reed biomass: Effect of pretreatment using different steam explosion conditions. *Biomass and Bioenergy*, *95*, 84–91. https://doi.org/10.1016/j.biombioe.2016.09.021

Lötjönen, T., & Paappanen, T. (2013). Bale density of reed canary grass spring harvest. *Biomass and Bioenergy*, *51*, 53–59. https://doi.org/10.1016/j.biombioe.2012.12.041

Michel, F., O'Neill, T., Rynk, R., Gilbert, J., Wisbaum, S., & Halbach, T. (2022). Passively aerated composting methods, including turned windrows. In *The Composting Handbook* (pp. 159–196). Elsevier. https://doi.org/10.1016/b978-0-323-85602-7.00002-9

Miljö & Utveckling. (n.d.). Retrieved February 13, 2023, from https://miljo-utveckling.se/vattenbuffelslapp-har-jobbar-de-nya-naturvardarna/

Mola-Yudego, B., Xu, X., Englund, O., & Dimitriou, I. (2021). Reed canary grass for energy in sweden: Yields, land-use patterns, and climatic profile. *Forests*, *12*(7). https://doi.org/10.3390/f12070897

Naturvårdsverket. (n.d.-a). *Miljöbedömningar enligt kapitel 6 miljöbalken*. Retrieved April 4, 2023, from https://www.naturvardsverket.se/vagledning-och-stod/miljobalken/miljobedomningar/strategisk-miljobedomning/biologisk-mangfald-i-miljobedomning/artskydd-i-strategisk-miljobedomning/

Naturvårdsverket. (n.d.-b). *Utsläpp av klimatpåverkande gaser i Västra Götalands län*. Retrieved May 11, 2023, from https://sverigesmiljomal.se/miljomalen/begransad-klimatpaverkan/klimatpaverkande-utslapp/vastra-gotalands-lan/

Naturvårdsverket. (n.d.-c). *Vägledning om statliga bidrag till lokala naturvårdsprojekt*.

Naturvårdsverket. (2000). *Svenska tolkningar Natura 2000 naturtyper*.

Naturvårdsverket. (2011a). *Myrsjöar Naturligt dystrofa sjöar och småvatten Natural dystrophic lakes and ponds EU-kod: 3160 Länk: Gemensam text (namn och koder)*. http://www.naturvardsverket.se/upload/04_arbete_med_naturvard/vagledning/naturtyper/naturtypergemensam.pdf#2

Naturvårdsverket. (2011b). *Naturligt näringsrika sjöar, Vägledning för svenska naturtyper i habitatdirektivets bilaga 1*. http://www.naturvardsverket.se/upload/04_arbete_med_naturvard/vagledning/naturtyper/naturtypergemensam.pdf#2

Naturvårdsverket. (2011c). *Vägledning - Ävjestrandsjöar*. http://www.naturvardsverket.se/upload/04_arbete_med_naturvard/vagledning/naturtyper/naturtypergemensam.pdf#2

Naturvårdsverket. (2011d). *Vägledning - Kransalgssjöar*. http://www.naturvardsverket.se/upload/04_arbete_med_naturvard/vagledning/naturtyper/naturtypergemensam.pdf#2

Niemiec, M., Paluch, L., Gródek-Szostak, Z., Szeląg-Sikora, A., Sikora, J., & Mudryk, K. (2019). Evaluation of the environmental and economic aspects of the use of common reed from eutrophic lakes for energy purposes. *IOP Conference Series: Earth and Environmental Science*, *214*(1). https://doi.org/10.1088/1755-1315/214/1/012117

Norrman, J., Belhaj, M., Arnell, J., Svenska, I., Svensén, M. B., & Larsson, H. (2005). *Biogas som drivmedel för fordon i Västra Götaland*. www.ivl.se,

Novobilsky, A., Christiansson, D., & König, U. (2012). *Stora leverflundran i fokus runt mötesbordet*. www.svdhv.se

Oleszek, M., & Matyka, M. (2020). Energy Use Efficiency of Biogas Production Depended on Energy Crops, Nitrogen Fertilization Level, and Cutting System. *Bioenergy Research*, *13*(4), 1069–1081. https://doi.org/10.1007/s12155-020-10147-2

Paulrud, S., Roslund, C. W., & Jordan, S. (2021). *BIOEKONOMI OCH HÄLSA PROCESS-OCH SYSTEMANALYS Samverkan kring energigrödor, slam och aska i kretslopp*.

Pederson, H. (2023, March 30). *Interview landowner*.

Pettersson, E. (2023). *Interview The Royal Swedish Agricultural Academy*.

Prade, T., Svensson, S.-E., & Tufvesson, L. (n.d.). *Skördad våtmarksvegetation renar vattnet bättre från närsalter!*

Renewable Energy Agency, I. (2018). *Biogas for Road Vehicles: Technology brief*.

Rörflensodlarna. (n.d.). *Egenskaper rörflen*. Retrieved February 3, 2023, from http://vatmarksguiden.se/projekt/rorflen/

Rynk, R., Cooperband, L., Oshins, C., Wescott, H., Bonhotal, J., Schwarz, M., Sherman, R., & Brown, S. (2022). Why compost? In *The Composting Handbook* (pp. 1–26). Elsevier. https://doi.org/10.1016/b978-0-323-85602-7.00001-7

Samhällsekonomiska kostnader, transportsektorn. (n.d.). Retrieved April 3, 2023, from https://www.trafa.se/globalassets/pm/2020/pm-2020_1-transportsektorns-samhallsekonomiska-kostnader---bilagor.pdf

SCB. (n.d.-a). *Land- och vattenareal per den 1 januari efter region och arealtyp. År 2012 - 2023*. Retrieved April 21, 2023, from

https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__MI__MI0802/Areal2012NN/
SCB. (n.d.-b). *Land- och vattenareal per den 1 januari efter region och arealtyp. År 2022*. Retrieved January 30, 2023, from Land- och vattenareal per den 1 januari efter region och arealtyp. År 2012 - 2022
Scordia, D., & Cosentino, S. L. (2019). Perennial energy grasses: Resilient crops in a changing european agriculture. In *Agriculture (Switzerland)* (Vol. 9, Issue 8). MDPI AG. https://doi.org/10.3390/agriculture9080169
Sgroi, F., Di Trapani, A. M., Foderà, M., Testa, R., & Tudisca, S. (2015). Economic performance of biogas plants using giant reed silage biomass feedstock. *Ecological Engineering*, *81*, 481–487. https://doi.org/10.1016/j.ecoleng.2015.04.068
Shinners, K., & Friede, J. (2018). Energy requirements for biomass harvest and densification. *Energies*, *11*(4). https://doi.org/10.3390/en11040780
Slepetiene, A., Ceseviciene, J., Amaleviciute-Volunge, K., Mankeviciene, A., Parasotas, I., Skersiene, A., Jurgutis, L., Volungevicius, J., Veteikis, D., & Mockeviciene, I. (2023). Solid and Liquid Phases of Anaerobic Digestate for Sustainable Use of Agricultural Soil. *Sustainability*, *15*(2), 1345. https://doi.org/10.3390/su15021345
SLU. (n.d.). *Artfakta* . Retrieved April 4, 2023, from https://artfakta.se/naturvard/filter
SMHI. (2022, March 31). *Allmänt om Sveriges sjöar*. https://www.smhi.se/kunskapsbanken/hydrologi/sveriges-sjoar/sveriges-sjoar-1.4221
st1 Biogas. (n.d.). Retrieved May 8, 2023, from https://www.st1biogas.se/priser
Statens Veterinärmedicinska anstalt. (n.d.). Retrieved April 24, 2023, from Statens Veterinärmedicinska anstalt
Stockholm Exergi. (2023). *Miljönyckeltal Stockholm Exergi 2022*.
Suardi, A., Stefanoni, W., Alfano, V., Bergonzoli, S., & Pari, L. (2020). Equipping a combine harvester with turbine technology increases the recovery of residual biomass from cereal crops via the collection of chaff. In *Energies* (Vol. 13, Issue 7). MDPI AG. https://doi.org/10.3390/en13071572
Suter, W. (1994). Overwintering waterfowl on Swiss lakes: how are abundance and species richness influenced by trophic status and lake morphology? *Hydrobiologia*, *279–280*(1), 1–14. https://doi.org/10.1007/BF00027836
Sverige Bioekonomiutredningen., & Elanders Sverige AB. (n.d.). *Förnybart i tanken : ett styrmedelsförslag för en stärkt bioekonomi*.
Sveriges Riksdag. (n.d.). *Artskyddsförordningen (2007:845)*. Retrieved April 4, 2023, from https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/artskyddsforordning-2007845_sfs-2007-845
Trafikanalys. (2022). *Fordon i län och kommuner 2021*.
Trisos (south Africa,), Romero, J., Dodman, D., Geden ; Bronwyn, O., & Pörtner, H. ; H.-O. (2023). SYNTHESIS REPORT OF THE IPCC SIXTH ASSESSMENT REPORT. In *Diriba Korecha Dadi*. Panmao Zhai.
Turistrådet Västsverige. (n.d.). *Tydjesjön - Fågelsjö i förändring*. Retrieved January 26, 2023, from https://www.vastsverige.com/dalsland/boken-natur-i-dalsland/artiklar/vanerkusten-248-277/62.-tydjesjon---en-del-av-boken-natur-i-dalsland/
United Stated Environmental Protection Agency. (n.d.). Retrieved April 3, 2023, from https://www.epa.gov/sustainable-management-food/types-composting-and-understanding-process
van der Sluis, T., Poppens, R., Kraisvitnii, P., Rii, O., Lesschen, J. P., Galytska, M., Elbersen, W., & Wageningen, A. (2013). *Reed harvesting from wetlands for bioenergy Technical aspects, sustainability and economic viability of reed harvesting in Ukraine*. http://www.agentschapnl.nl/en/programmas-regelingen/sustainable-biomassDBI01010

Våtmarksguiden. (n.d.-a). *Bladvass*. Retrieved February 2, 2023, from http://vatmarksguiden.se/projekt/bladvass/

Våtmarksguiden. (n.d.-b). *Jättegröe*. Retrieved April 24, 2023, from http://vatmarksguiden.se/projekt/jattegroe/

Våtmarksguiden. (n.d.-c). *Kaveldun*. Retrieved February 8, 2023, from http://vatmarksguiden.se/projekt/bredkaveldun/

Våtmarksguiden. (n.d.-d). *Rörflen*.

Våtmarksguiden. (n.d.-e). *Starr*. Retrieved April 25, 2023, from http://vatmarksguiden.se/projekt/starr/

Vattenmyndigheten. (2011). *En liten bok om vatten*.

Verheijen, F., Jeffery, S., Bastos, A. C., van der Velde, M., & Diafas, I. (2010). *Biochar Application to Soils*.

Verma, R., Badole Panjabrao Deshmukh Krishi Vidyapeeth, W., & Singh Meena, V. (2014). *Carbon and weight loss during composting of wheat straw by different methods*. https://www.researchgate.net/publication/286191585

Wahlström, N. (2023). *Interview with Niklas Wahlström*.

Weber, K., & Quicker, P. (2018). Properties of biochar. In *Fuel* (Vol. 217, pp. 240–261). Elsevier Ltd. https://doi.org/10.1016/j.fuel.2017.12.054

WWF, & ZSL. (2022). *Living planet report 2022*.

Yahya, S. Al, Iqbal, T., Omar, M. M., & Ahmad, M. (2021). Techno-economic analysis of fast pyrolysis of date palm waste for adoption in Saudi Arabia. *Energies*, *14*(19). https://doi.org/10.3390/en14196048

Zhang, B., Joseph, G., Wang, L., Li, X., & Shahbazi, A. (2020). Thermophilic anaerobic digestion of cattail and hydrothermal carbonization of the digestate for co-production of biomethane and hydrochar. *Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering*, *55*(3), 230–238. https://doi.org/10.1080/10934529.2019.1682367

ACKNOWLEDGEMENTS

We would like to thank Göran Berndes, our supervisor and examine, for excellent support throughout the thesis writing. Your guidance made it possible for us to manage all challenges faced during our master thesis project. A special thank also to Christel Cederberg for inspiring us in the early thesis phase. Furthermore, we would like to thank the reference group in this thesis project; Eva Pettersson (KSLA), Niklas Wahlström (Åmåls kommun), Fredriksson (Länsstyrelsen), Peter Saarikoski. We would also like to thank Arne Linding from LVR Våtmarksrestaurering for eager and inspiring conversations about lake meadow restorations. We would also like to acknowledge the rest of the master students at SEE, for thesis dialogues and other memorable moments.

Appendix A – Individual data for common reed, reed canary grass and cattail

Table 11. Common reed (Phr. australis)

	(Carson et al., 2018)	(Niemiec et al., 2019)	(Granéli, 1984)	(Cubars & Noviks, 2012)	(van der Sluis et al., 2013)	(Köbbing et al., 2013)	(Hultberg et al., 2018a)	(Komulainen et al., 2008a)	(Lizasoain et al., 2016)
Energy density (kJ/g)	17.2 ± 0.9	17.5 – 17.69 *(combustion heat value)* 16.24-16.67 *(working calorific value)*	18 000 kcal/kg			16.2	13		
C content (%, DM)				41.9 - 43.8			42.3		
N content (%, DM)	2.14 ± 0.52	0.875-1.625					1.89 ± 0.058		
P content (%, DM)	0.10 ± 0.02	0.115-0.284					0.18 ± 0.09		
Yield (t DM/ha/yr)		6.22-16.28			3.6-43.5	5 *(South Sweden 2012)*	12.4-13.7		
Ash content (%)		8.12-10.13						Approx. 4%	
Volume *Compressed into bales* (kg/m^3)						20-40 (natural state) 140-170 (bales) *moisture content 20%			
Biogas potential (L CH4/kg VS)									302

Table 12. Reed canary grass (Pha. arundinacea)

	(Carson et al., 2018)	(Paulrud et al., 2021)	(van der Sluis et al., 2013)	(Heinsoo et al., 2011)	(Lötjönen & Paappanen, 2013)	(Scordia & Cosentino, 2019)	(Dubrovskis et al., 2009)
Energy density (kJ/g)	20.3 ± 1.1	15.4-16.4 18.2-18.4 kJ/g DM		16.93-17.18 (Sweden 17.6)			
C content (%, DM)		48.4-48.5		46.7-47-4			
N content (%, DM)	1.51 ± 0.07	1.40-1.62		0.9-0.96			
P content (%, DM)	0.30 ± 0.03	0.13-0.14					
Yield (t DM/ha/yr)			3.5-22.5	Autumn: 12.7 (mineral) 7.2 (organic soils) July: 5.5			
Ash content (%)				2.3-5.1			
Volume *Compressed into bales (*kg/m^3)					60-80 (chaff) 80-200 (round bales) 130-180 (large square bales) *moisture content 10-15%	163 (round bales)	
Biogas potential (L CH4/kgVS)							263

Table 13. Cattail (Typha x glauca)

	(Carson et al., 2018)	(van der Sluis et al., 2013)	(Bansal et al., 2019)	(Grosshans et al., 2014)	(Zhang et al., 2019)
Energy density (kJ/g)	16.0 ± 0.8				
C content (%, DM)					
N content (%, DM)	1.13 ± 0.13				
P content (%, DM)	0.17 ± 0.02				
Yield (t DM/ha/yr)		4.8-22.1	10-30		
Ash content (%)					
Volume (kg/m^3)				182 (large square bales)	
Biogas potential (ml CH4/gVS)					230-280

APPENDIX B – Interviews with landowners around Tydjesjön

INTERVIEW 1 – LAND USER

1. **What are your thoughts about Lake Tydjesjön and its regrowth?**

It’s sad that nothing happens if you don't take care of it. A lot of reeds, which leads to less abundant birdlife. Also becomes a boring environment visually.

2. **What are you doing with your land today? Is it somehow managed? Have you managed it differently in the past during your ownership?**
   a. **If you manage the land today – how is it managed? Mowing for feed, grazing or otherwise?**
   b. **If you don't manage the land today – how come?**

Managing it today performed with grazing, cattle.
A risk is that the animals can descend into the lake (3 animals in total so far)
More and more grazing areas are needed every year. Last year 60 animals were grazing these lands. In the beginning one talked about that the animals learned where they can walk and not, but require that it is nursing cows that live for several years, but in reality, they live maximum of 2 seasons so therefore they have no time to learn.
All the land they are using today, have grazing animals on them.

3. **Do you have the possibility (knowledge, machines, etc.) to manage the lake meadow? Specifically, given the difficulty of managing very wet soil.**

They have thought about managing the land with machines, but have no machines ourselves that can manage this type of land which is so wet.
One year they tried to burn up the reeds, but it was difficult to get it to burn, and once it burned, there were several alarms to the fire department, who demanded that they stop burning or pay for emergency services.
It is difficult to know how much bearing capacity the land has, and how much heavy machinery required can be used for mowing. They have also looked into hiring help, contracting, but have not found a good match. It is expensive and it is also challenging to find someone who has the time. If you find someone who can mow and leave the biomass directly on the grand and in the water, it can create downstream problems where the streams are clogged, this also leaves you responsible. Costs are twice as high if the contractor should take care of the reed and not just cut it and leave it. The contractors who we have talked to, collect the biomass with hay tail and let lie in a pile at the edge of the meadow, where there is no risk that the pile is reached by the water at high tide.
They have thought about grazing on the north side, but need to know that there are enough grazing animals for that area. The animals are eating more and more every year. The more the reeds disappear, the more the soil take up water and vegetation changes.
Animal grazing in these lands requires moving the animals around during the season. The first year the animals grazed on the same land, eating the tastiest grass. For them to into the water and graze, they must be hungry so that they choose to eat the reed. Therefore, they have divided the land into 8 gills, and 2 groups of animals on each, which they have in three-week intervals. The animals need to be moved around 1 time per week. There are also challenges that the water level in the lake rises and falls. This can lead to that the electricity in the fence can stop working at high tide, and at low water the animals can go around the electric fences instead and therefore need to be moved out.
What takes the most time is that the animals require daily supervision, and the land is not so easily accessible.

4. **What positive aspects do you see in managing a lake meadow?**

Birdlife.
But it is also fun with a challenge, to manage a land nobody believes can be managed. However, the best thing is that landowners really appreciate the increased better landscape picture when the reeds disappear, and it becomes more open.

5. **What incentives would cause you to manage the lake meadow/keep it open? (ex. Nature conservation value, Cultural history, Economic gain, Biodiversity, Climate benefit or other)**

That you do something for nature, biodiversity. But of course you also have to make money from the animals, so you need some type of support so that you can have financial sustainability. The animals have to eat, and they pay for the pasture.
Requires that it go together – a prerequisite.

6. **Have you applied for a grant for the care of lake meadows?**
    a. **No - Would you consider applying for a grant to keep the lake meadow open? Do you know what contributions there are? What are the obstacles to applying?**
    b. **Yes – What complicated to search? Is it possible to access the application? Was any control done by the County Administrative Board or the Swedish Board of Agriculture as a follow-up? How much support did you get?**

It was not easy. However, applied for pasture restoration at Jordbruksverket. For the application one had to draw land on a map to estimate the amount of land that the animals might graze on and for which you want compensation. The land should not have been grazed recently, but there could have been grazing animals on the land in the past.
You must make an assessment of how close to the water the animals should be able to walk and graze. If you think they should graze 20 ha, then you have 5 years' time to make sure that they will graze all 20 ha, but if only 15 ha is grazed by the end of the project, then you will have to repay the funding given.
I would rather like to show that this is the lake meadow, get 5 years to get the animals to graze, and if you do not succeed, the project is terminated.
The risk now is that if you overestimate –you will have to repay, and if you underestimate, you will not have enough money to cover your costs. The landowner is responsible for what you apply for.
After the application the landowner will get a visit from advisors from Länsstyrelsen, who will come and check if land has separate values. If it is estimated to have that, then you can get a grant. Even the one at Länsstyrelsen thought it was pure guesswork. The advisor will also estimate the biodiversity gains during this visit.
Then the work begins with a 5 annual plans with sub-goals per year, where the final goal should be ready after 5 years. Then Länsstyrelsens administrators visits to check if special values exist, if red-listed species exist, etc. If you, you can get additional fundings, and receive another 5 years of compensation.
One must apply again every year, via Jordbruksverket SAM internet. You get lower compensation for restoration, 3 200 SEK/ha. 6 000 SEK/ha if you get special values, 3500 SEK/ha for general values.
Now you can apply via NVV (LOVA/LONA)

7. **How much profit do you think is required per hectare for it to be worth taking care of the lake meadow?**

Should be at the level of 6000 SEK/ha level for it to be worth it.
Some leases from landowners – in some cases that is free of charge to maintain the land and avoid regrowth. However, some want compensation, around SEK 500 SEK / ha, but would really like more.

Katrin, at Länsstyrelsen, 15 years ago, did nature conservation projects with animals that Länsstyrelsen would manage. She contacted animal owners, but then the project money ran out and it fizzled out. Then Catrin ended her employment at Länsstyrelsen. After that, the opportunity to apply for compensation for restoration projects came up. That's how my work started.
There is a new technology where you put electronic collars on the animals (virtual fences), but this is not approved in Sweden yet. That would have facilitated a lot to avoid work with moving the fences.
In my project, I cannot seek more money to get the animals to graze further out. Neither is it possible to apply for more money to restore further out, and if it is to be maintained, I am responsible for the cost of the machinery myself. It is up to each landowner to take the initiative; Länsstyrelsen does not push it.
If I hadn't had the support of Katrin, I wouldn't have applied for the funding.
Länsstyrelsen only writes a report, for instance “We think they should save a certain type of tree, it should look like this, etc...” But then it's up to each landowner to interpret this and try to mimic it, which can be difficult.
In the application – is it necessary to state anything about biodiversitys, how the project can affect this?
No – it's Länsstyrelsens advisor alone that gives the commitment plan. “Found this and this species, and if you do this, it will benefit...” Same applies to restoration. One receives information from Länsstyrelsen before the project starts if the land will become a land with general or special values.
I would have liked if it was not special or general values, but the same for all. The lake meadow - in order to receive support from Jordbruksverket, it is required that there is food for the animals to graze. But a lake meadow can flood and look different year after year. Then it will be grass-poor lands, which provide lower compensation. 3700 SEK/ha.
How long are they required to keep the lake meadow open after applying?
Over the 5-year period, 20 years or other= 5-year period
Restoration = Commits to 10 years.

8. **How would you most like the lake meadow to be managed? With animals? With machines?**

A combination. The years when there is a lot of water and a high-water level, it becomes difficult for the animals' graze far out on the meadow. The water needs todraw back for the animals to reach those parts at least once. There is no food value in that reed, it is only trampled down. Therefore, old reed needs to be removed. If you remove everything in one year, then the animals do not have time to eat everything, so therefore you need to harvest it step by step.
The biomass would have been interesting with biogas, for example.
Whether you bring in a contract to cut – would think around 10 ha, depends on the contractor.
I would like harvest in some areas, eg 10 ha in one area where there is a good chance for the animals to graze. It is a trade-off to use contractors, from a financial point of view. The closest contractor is located 10 swedish mil away and would imagen they want a week to accept the project, at least10 days of work for them to be able to accept it. For it to be good, timing is required. Low water is hard to say when in the year this occurs. It may not coincide with the breeding period. In other words, it is difficult to plan a day to perform the work, as many parameters should be considered. It would probably be possible to rent a machine, for a one time job, and after that, the animals would probably be able to keep the area free by grazing.
Requires a collaboration with several local animal owners. If you are going to carry it out, for example, 40 ha of clearing would require about 40 animals. I currently have about 80 animals in total. 40 animals = 40 hectares (20)

9. **How much area of lake meadow do you own/have access to? Is this area large enough for it to be worth working the land?**

Seems to be a lot about going break-even on the bait, no requirement to make a profit.

INTERVIEW 2 – LANDOWNER

1. **What are your thoughts about Lake Tydjesjön and its regrowth?**

I am aware of this. In the 60s I used to fish a lot; however it grew too much in the 70s. This affected fishing, etc.
Bäckströms, who are using land around the lake and support landowners, they manage lake meadows with animals. This has possibly changed the landscape to some extent.
Mikael Bertilsson 0706-75 53 37 has land on the east side.

2. **What are you doing with your land today? Is it somehow managed? Have you managed it differently in the past during your ownership?**
    a. **If you manage the land today – how is it managed? Mowing for feed, grazing or otherwise?**
    b. **If you don't manage the land today – how come?**

I have forest land all the way to the lake meadow when water is high.

3. **Do you have the opportunity (knowledge, machines, etc.) to manage the lake meadow? Specifically, given the difficulty of working very wet soil.**

4. **What positive aspects do you see in managing a lake meadow?**

Better for biodiversity, you get richer wildlife. It is sad when it gets wild and regrow. If it is managed well, it also decreases floodings of västanån and vitlandaån.
It used to be a rich bird lake, however I haven't seen any reductions in birds.

5. **What incentives would cause you to manage the lake meadow/keep it open? (ex. Nature conservation value, Cultural history, Economic gain, Biodiversity, Climate benefit or other)**

6. **Have you applied for a grant for the care of lake meadows?**
    a. **No - Would you consider applying for a grant to keep the lake meadow open? Do you know what contributions there are? What are the obstacles to applying?**
    b. **Yes – What complicated to search? Is it possible to access the application? Was any control done by the County Administrative Board or the Swedish Board of Agriculture as a follow-up? How much support did you get?**

7. **How much profit do you think is required per hectare for it to feel worth taking care of the lake meadow?**

8. **How would you most like the lake meadow to be managed? With animals? With machines?**

Animals that are the nicest, as long as they do not descend into the lake. It is mostly cattle that walk there today, but have walked sheep around it as well.

9. **How much area of lake meadow do you own/have access to? Is this area large enough for it to be worth working the land?**

INTERVIEW 3 – LAND USER

1. **What are your thoughts about Lake Tydjesjön and its regrowth?**

There has been made attempts to open up around the lake, there has run mower around the lake on some occasion, but it is difficult to keep it open in the long run. From my property, I don't see the lake as the forest in between.

2. **What are you doing with your land today? Is it somehow managed? Have you managed it differently in the past during your ownership?**
    a. **If you manage the land today – how is it managed? Mowing for feed, grazing or otherwise?**
    b. **If you don't manage the land today – how come?**

I am living on our family farm since many generations back. Previously the land was managed by her husband, but now a neighbor rents the land and manages it well for her. The land by the lake is a lot of mountains and a little forest. The thought is that nature gets to have its course there. Some of the land is managed and harvested, but the rest is natural land. Mikael leases the land. Mikael grows to some extent and clears a little. Gunnar, her husband, didn't take care of mkt either.

3. **Do you have the opportunity (knowledge, machines, etc.) to manage the lake meadow? Specifically, given the difficulty of working very wet soil.**

No.

4. **What positive aspects do you see in managing a lake meadow?**

Don't have the knowledge to do it and isn't interested in maintaining it herself. There is no disadvantage in letting nature take care of it, birds benefit from letting nature have its own course.

5. **What incentives would cause you to manage the lake meadow/keep it open? (ex. Nature conservation value, Cultural history, Economic gain, Biodiversity, Climate benefit or other)**

Birdlife could be gained which is nice.

6. **Have you applied for a grant for the care of lake meadows?**
    a. **No - Would you consider applying for a grant to keep the lake meadow open? Do you know what contributions there are? What are the obstacles to applying?**
    b. **Yes – What complicated to search? Is it possible to access the application? Was any control done by the County Administrative Board or the Swedish Board of Agriculture as a follow-up? How much support did you get?**

7. **How much profit do you think is required per hectare for it to feel worth taking care of the lake meadow?**

8. **How would you most like the lake meadow to be managed? With animals? With machines?**

9. **How much area of lake meadow do you own/have access to? Is this area large enough for it to be worth working the land?**

A number of years ago, there was talk about an EU projects to manage the lake and lake meadows, but it grew too big and we stopped it, as we did not want to have cattle on the land that Mikael uses and harvests.

INTERVIEW 4 – LAND USER

1. **What are your thoughts about Lake Tydjesjön and its regrowth?**

The lake has never been so open as after the gray geese arrived. First came the Canada geese, then the gray geese (which had come to Lake Tydjesjön for a year).
He has been hunting ducks and geese for 20 years around the lake of Tydjesjön, and 20 years ago it was completely overgrown (rode in canals around the lake).
The geese keep away the reed, eat the reed under the surface of the water, and then water comes down in the pipes and kills the reed. Geese come naturally. It is mainly surface meters out in the open water that have been affected there, not the lake meadow.
If you do it yourself, you need to mow it.

2. **What are you doing with your land today? Is it somehow shot? Has it looked different in the past during your ownership?**
    a. **If you manage the land today – how is it managed? Mowing for feed, grazing or otherwise?**
    b. **If you don't manage the land today – how come?**

He's had grazing animals before, but not in recent years. Had problems with horseflies and "klägg", the animals didn't feel so good down there, so now he clears the surface once a year, by tractor. This cutting and clearing is not so close to the water, however, has some reed closest to the water that he cannot access and where the reed is left. Cutting and clearing is done as close to the water as he can.
He has the north side, but on the south side it is a completely different shoreline since it is grazed there. He has previously leased that land (on the south side). Today he has only meat animals and has no need to use the lake meadow for grazing for his 30 animals, he has different land to graze and no incentive to claim the land.

3. **Do you have the opportunity (knowledge, machines, etc.) to manage the lake meadow? Specifically, given the difficulty of working very wet soil.**

Have no money to bring in contracting to beat the reeds that exist.
Leaving the reeds lingering. Very few who take care of the reeds are his image, and that most of the reeds remain. Special machines are required, and then the cost arm increases.

4. **What positive aspects do you see in managing a lake meadow?**

It is positive visually as it looks better.
Wild boars like to hide in the reed, so as a hunter it is nice to be able to hunt, however from an agricultural perspective, they are not wanted.

5. **What incentives would cause you to manage the lake meadow/keep it open? (ex. Nature conservation value, Cultural history, Economic gain, Biodiversity, Climate benefit or other)**

He does not have time today to manage the lake meadow more. Has forest, machines, sawmill, agriculture and family. Not sure how to manage all. Neither does he see much gain in taking care of the reed. Large liver flaps thrive very well in such lands. If you get it into the animals, you get big problems, and this is also a to let the animals graze in this type of land. Nutritionally, the reed is not the best either.
He would not be interested either if you were to send away the biomass for other things such as biogas, but if there is a high enough price for the raw material to be able to take in a contract then maybe.

6. **Have you applied for a grant for the care of lake meadows?**

a. **No - Would you consider applying for a grant to keep the lake meadow open? Do you know what contributions there are? What are the obstacles to applying?**
b. **Yes – What complicated to search? Is it possible to access the application? Was any control done by the County Administrative Board or the Swedish Board of Agriculture as a follow-up? How much support did you get?**

No – have not applied.
Don't think it's relevant to apply either as the lands he manages today are too far from the water.

7. **How much profit do you think is required per hectare for it to feel worth taking care of the lake meadow?**

The fundings are SEK 1500 / ha on ordinary land. He would have liked to have additionally about 1 000 SEK / ha for it to be relevant to manage, even with a contractor were he didn't have to do anything, after costs for contractors were paid.

8. **How would you most like the lake meadow to be managed? With animals? With machines?**

Don't think anything other than machines would be relevant to bring down the reeds. Then thereafter it could be maintained with animals, but the restoration itself should require mechanical removal of the thick reeds that grow today.

9. **How much area of lake meadow do you own/have access to? Is this area large enough for it to be worth working the land?**

DEPARTMENT OF SPACE, EARTH AND ENVIRONMENT
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023-
www.chalmers.se