Sustainable use of Baltic Sea natural resources based on ecological engineering and biogas production

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Abstract

Eutrophication is a major threat to the Baltic Sea, causing algae blooms and hypoxic bottoms. Ecological engineering methods aiming at help mitigating the nutrient imbalance problems have already been initiated or are being planned in the coastal zones of the Baltic Sea. This includes harvesting of reed, macro algae and blue mussels as nutrient and energy natural resources. The potential and feasibility of such methods to form the basis for sustainable use of natural resources is governed by the ecological, technical, economic and social aspects associated with the whole chain of processes from biomass to end products, e.g. biogas, fertilizers, and wastes. As a first step in a sustainability assessment, we show that biogas production from algae and reed is associated with a net energy benefit. Blue mussels do not result in a net energy benefit if used for biogas production, but represent the most efficient way of removing nutrients. Based on these preliminary results, we suggest that biogas production from reed and macro algae is worthy of further investigation, whereas for blue mussels, an alternative product must be found.
Keywords: eutrophication, ecological engineering, biogas, LCI, Baltic Sea, reed, blue mussel, macro algae.

1 Introduction

Eutrophication is one of the most serious environmental threats to the Baltic Sea, resulting in algae blooms and hypoxic bottoms (Bernes [1]). Despite the measures taken, eutrophic conditions still persist, due to extensive internal recycling of nutrients (e.g., Conley *et al.* [2]; Savchuk and Wulff [3]), leaching from upstream subsurface pools (e.g., Darracq *et al.* [4]), and unmanaged,

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diffuse anthropogenic sources. Today, a number of large-scale, ecological engineering initiatives to recover biomass (e.g., mussels, algae and reed) that thrive under the present eutrophic conditions from the Baltic Sea have been initiated or are being planned (see, for example, Section 1.1). These activities aim at locally balancing the nutrient flows thereby mitigating the eutrophication problems, removing biomass for biogas production or retrieval of energy by other means, removing nuance from algae blooms, or retrieving natural resources for alternative products, such as fertilizers, at the same time reducing CO_2 emissions, thereby providing a positive climate effect.

The potential and feasibility of ecological engineering methods to form the basis for sustainable use of natural resources, through recovery of biomass from the Baltic Sea, is governed by the ecological, technical, economic and social aspects associated with the whole chain of processes from biomass to end products, e.g. biogas, fertilizers, and wastes. The objectives of this work are to:

- Compare the efficiency of reed and macro algae harvesting and mussel farming with respect to nutrient removal from the Baltic Sea;
- Provide and compare energy budgets for the full process chain from harvesting of biomass to biogas production for reed, macro algae and mussels;

As first steps in a sustainability evaluation of ecological engineering methods to recover biomass nutrient resources from the Baltic Sea. We will also present the Trelleborg Concept, which aims at reducing the nutrient load to the Baltic Sea in a low-intensity but steady manner through the use of a combination of different ecological engineering methods.

1.1 The Trelleborg concept

Ecological Engineering constitutes the part of Environmental Technology that designs societal services such that they benefit society and nature, where the design should be systems based, sustainable, and integrate society with its natural environment. Its applications reach from construction of new ecosystems to ecologically sound harvesting of existing ecosystems in order to solve environmental problems (Mitch and Jorgensen [5]). Today, a number of large-scale, ecological engineering initiatives to recover biomass from the Baltic Sea have been started or are being planned in Trelleborg, Sweden.

The municipality of Trelleborg, situated at the south coast of Sweden and which has Sweden's richest soils and thus very extensive farming, aims to serve as a model for sustainable development in the southern part of the Baltic Sea Region (Gröndahl and Müller [6]). Together with local farmers and landowners, Trelleborg will establish large-scale biogas production facilities based on new wetlands established along the coastal zone of southern Sweden. Growth and harvesting of bio-energy (e.g. reed belts and submerged vegetation) will take place within these wetlands. Trelleborg will use the biogas for transportation fuel, heating of domestic houses in urban areas and local production of electric power (Gröndahl and Müller [6]).

The nutrients reaching the coastal waters of the southern Baltic Sea from other sources, e.g. traffic or sewage treatment, and from other geographical areas will be removed with new technology for collecting macro algae from the sea. The biomass collected will be used for biogas production. The digestor residues from the biogas plant can contain heavy metals but there are existing techniques to remove these metals from the residues, which can then be used as fertilizer on arable land, resulting in nitrogen and phosphorus recycling (Gröndahl and Müller [6]). During summers with extensive blooms of Cyanobacteria, surface accumulations of *Nodularia spumigena* will be harvested and used for biogas production. However, the residues will not be suitable as an agricultural fertilizer since they may contain toxic substances (Gröndahl [7]).

In addition to the establishment of wetlands in the coastal area and harvesting of algae, aquaculture of the blue mussel *Mytilus edulis* may be a way to indirectly remove nutrients from the Baltic Sea. *Mytilus edulis* is very efficient at filtering and removing micro algae from the water column. Several successful trials of this method have been conducted on the west coast of Sweden, but the method may also be useful in the Baltic Sea (Lindahl *et al*. [8])

All these new means to remove nutrients from the highly eutrophied Baltic Sea in a low-intensity but steady process could bring about a much-needed reduction of the anthropogenic nutrient flow if they were to achieve widespread use among the cities around the Baltic Sea. The Trelleborg Concept of transforming a problem into a resource by preventing eutrophication through biogas production may have a number of benefits for the environment in the region (Gröndahl and Müller [6]), e.g.,

- Biogas means less CO_2 thereby decreasing the climate change;
- Harvesting of macro algae and *Cyanobacteria* will remove nutrients and heavy metals from the Baltic Sea and improve local beaches for recreational purposes;
- When shallow coastal waters are cleansed from oxygen-depleting, decaying macro algae, areas will again become available to sustain the growth of juvenile fish.

2 Methods

2.1 Nutrient efficiency

A simple comparison of the nutrient removal from the different harvested biomasses was made. This comparison was based on the nutrient contents expressed on wet and dry weight basis as compiled from the literature. Here, we report data based on wet weight, as this equals the live weight of the organisms, and thereby the mass handled in the processes.

2.2 Energy budget

This work was based on a Life Cycle Inventory (LCI) on biogas production from biomass from the Baltic Sea. This simple LCI was carried out from an energy perspective and took the form of an energy budget resulting in a net energy benefit/loss for each biomass. This budget included the energy potential of the biomass combined with the energy demand along the full process chain from biomass harvesting to biogas production. In order to allow for comparison of the net energy from the different biomasses in an eutrophication perspective, the energy budget was performed based on a unit mass of nitrogen (1 tonne N) from the biomass. The analysis is detailed by Karlsson [9] and was conducted based on compilation of literature information and stakeholder interviews.

2.2.1 Energy potential

The energy potentials of the different biomasses were estimated based on the methane yield in the biogas production in combination with the energy content of methane, together with the nitrogen and volatile solids content of the biomass, as compiled in Table 1.

2.2.2 Energy demand

The energy demand was quantified along the whole chain of processes from biomass harvesting to biogas production involving:

- Harvesting
- Transport of biomass to the biogas production facility
- Biogas production

We excluded the handling of the digestate here, as this may potentially be used for other products, e.g., as liquid, agricultural fertilizer. We addressed harvesting of reed belts in the coastal zone and of surfacial macro algae along with long line farming of blue mussels.

For reed and macro algae, we assessed a case where harvesting is achieved with the aquatic plant harvester RS2000. We estimated the energy demand based on hourly diesel demand (~6 L h^{-1}; Salin [17]), hourly area harvested (algae 7 $x10^4$ and reed $4x10^4$ m^2 h^{-1}; Salin [17]), and wet weight biomass yield (corresponding to algae 0.13 and reed 0.25 kg dw m^{-2}; Fredriksson [14], Salin [17]). The energy demand for mussel harvesting include demands associated with boat ride (50 l diesel h^{-1}), idling and removal of mussels from the long line (15 l diesel h^{-1}), yielding $75x10^3$ kg wet weight of mussels per farm, with a harvesting and transport time of 30 and 2 hours, respectively (data from Granhed [18]).

Table 1: Methane yield, dry and volatile solids and nutrient content.

	Dry solids [kg dw kg^{-1} ww]	Nitrogen content [kg N kg^{-1} dw]	Volatile solids content [kg vs kg^{-1} dw]	Methane yield [l CH_4 kg^{-1} ww]
Algae	0.13[a*]	0.025[d*]	0.65[d]	200[d]
Reed	0.35[b]	0.009[e]	0.95[e]	180[e]
Mussels	0.02[c]	0.011[f]	0.86[c]	800[g]
Sludge	0.045[h*]	n.a.	0.68[h*]	625[h*]

[a]Fransson [10]; [b]Eno [11]; [c]Lim *et al.* [12]; [d]Davidsson and Ulfsdotter Turessson [13]; [e]Fredriksson [14]; [f]Haamer *et al.* [15]; [g]Recalculated from Lim *et al.* [12]; [h]Lantz [16]. n.a.- not addressed.
dw – dry weight, ww – wet weight, vs – volatile solids. *Average of reported values.

The transportation of biomass from the harvesting site to the biogas production facility was assumed to be by 4-tonne-trucks demanding 2.4 MJ tonne^{-1} ww km^{-1} (from 8 MJ tonne^{-1} dw km^{-1} for biomass with an average dry solid content of 30%; Berglund and Börjesson [19]). For simplicity, we addressed a case with 10 km transport distance.

As a first approximation, the energy demand within the biogas production facility was taken as 13% (heating) and 11% (electricity for milling, stirring, size reduction etc) of the energy in the produced biogas. This is based on a biogas production facility with a mesophilic digestion process using a blend of biomasses, with the values corresponding to on average energy demand for a typical biomass mix (Berlund and Börjesson [19]). In reality, the actual amount of energy needed will be affected by the choice of substrate.

3 Results and discussion

Figure 1 illustrates the nitrogen and phosphorous contents of algae, reed, and mussels. The phosphorous and nitrogen contents are approximately the same for algae and reed, whereas mussels have three times higher content of nitrogen and twice the amount of phosphorous. This shows that farming and harvesting of blue mussels is the more efficient way to remove nutrients from the Baltic Sea, compared to macro algae and reed. The high nutrient content of mussels is in accordance with reported results from several studies from the Swedish west coast (Lindahl *et al.* [8]). On the Swedish west coast, the blue mussels are relatively large and are thus suitable for human consumption making them economically valuable. This is not the case for the Baltic Sea, and thus there is a need to find alternative use of the mussels; in the following we test biogas production.

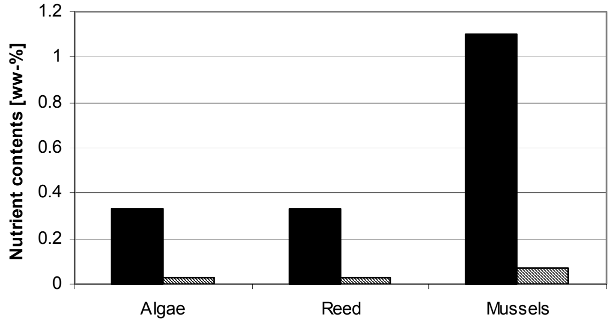

Figure 1: Nutrient content [ww-%] of algae, reed and mussels. Filled bars represent nitrogen and hatched bars represent phosphorous.

Figure 2 shows the energy content of algae, reed, mussels and sludge. We note that the energy contents of algae and mussels are similar to that of sludge, which is the most common substratum for biogas production. However, the highest energy content is found in reed, which contains around three to four times the energy of the other biomasses. This indicates reed as favourable for biogas production, in accordance with previous studies by e.g., Granéli [20] and Hansson and Fredriksson [21].

In Figure 3, the energy demand from harvesting, transportation and biogas production is shown. Here, we used a 10 km transport distance as a case. The energy input in the harvesting stage is nearly the same for algae and reed, but around ten times higher for mussels. The reason for this is the energy demanding machinery used during the harvest of mussels (personal communication with Granhed [18]).

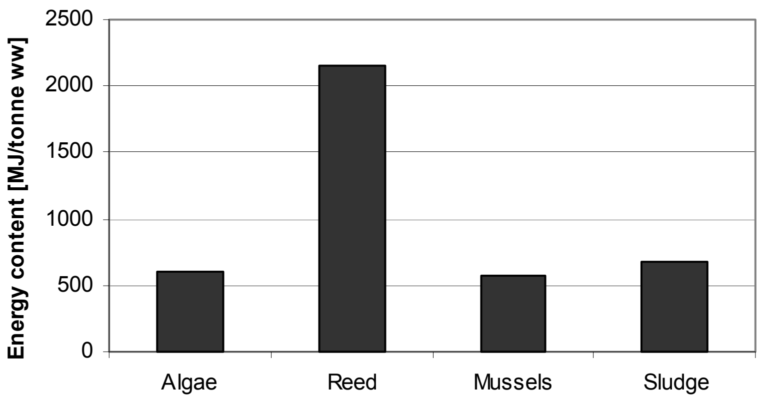

Figure 2: Energy content [MJ tonne^{-1} ww] of algae, reed, mussels, and sludge.

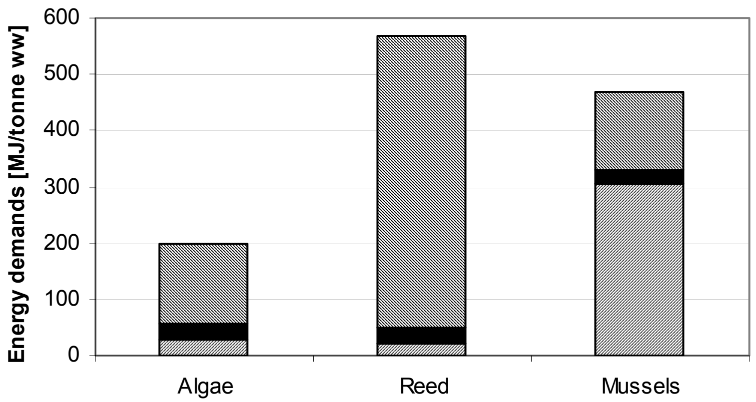

Figure 3: Energy demand [MJ tonne^{-1} ww] in harvesting (lower hatched area), transportation (intermediate black area), and biogas production (upper hatched area) for algae, reed and mussels.

The transport energy is the same for all three substrates. The energy demand in the biogas production process is nearly the same for algae and mussels. Reed, on the other hand, needs three-four times more energy. This follows upon the simplifying assumption that the energy demand in the biogas production step is proportional to the energy content of the biomass.

In Figure 4, a net energy balance for biogas production from algae, reed and mussels is shown. As the aim of the biomass harvesting from the Baltic Sea primarily was to remove nutrients, the energy balance is presented per unit mass of nitrogen removal by the different biomasses. Figure 4 shows that reed, despite a relatively high energy demand in the biogas production phase (Fig. 3), has the largest net energy benefit, followed by algae. Mussels have a close to zero net energy benefit, and with a small increase in transport distance from 10 km the net energy balance for mussels will be negative.

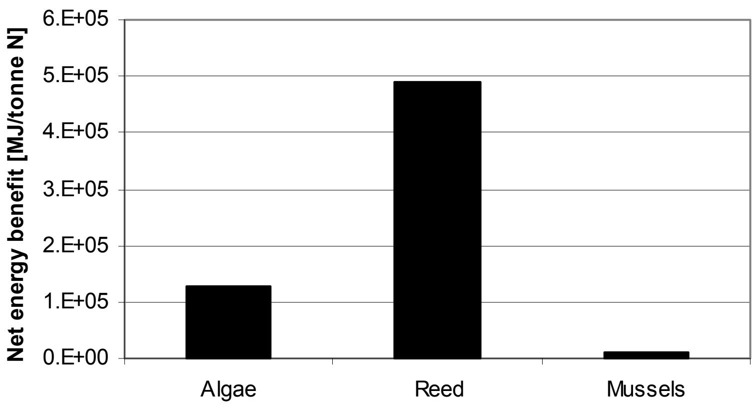

Figure 4: Net energy balance for biogas production from biomass from algae, reed, and mussels per unit mass of N [MJ $tonne^{-1}$ N].

4 Conclusion

In this study, we have assessed the nutrient removal efficiency of algae and reed harvesting along with mussel farming in the Baltic Sea. We also presented a net energy balance for biogas production from the biomasses. The results suggest that reed has the highest net energy benefit, followed by macro algae. Blue mussels are not suitable for biogas production, but are better than reed or algae when the ambition is to remove nitrogen or phosphorous from the Baltic Sea. Although preliminary, these results, as first steps in a sustainability evaluation of ecological engineering methods to recover biomass nutrient resources from the Baltic Sea, indicate that biogas production from reed and macro algae are worthy of further investigation. For blue mussels, an alternative product has to be found. Lindahl *et al.* [8] have suggested using blue mussels as chicken feed, for example.

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