Cluster On Anaerobic digestion environmental Services and nuTrients removAL

COASTAL BIOGAS

Guidance Report: Use of biogas as a tool to manage nutrient levels

December 2021

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Preface

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Cover photo

Collection of seaweed at Solrød Beach with a front loader. September 2019, Photo by Mikkel Busch, Solrød Municipality

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Summary

The report presents a tool that can be used to mitigate eutrophication in the Baltic Sea. The tool comprises the collection and utilisation of cast seaweed as a substrate for biogas plants and utilising the digestate as a fertiliser. The physical removal of cast seaweed is a powerful tool to mitigate eutrophication. Furthermore, a number of indirect benefits can be achieved by removing smelly seaweed from the beaches, which creates great benefits for coastal recreation and tourism.

1. Introduction to the report and eutrophication

The tool developed and presented in this report aims to be both holistic and multifunctional to achieve the greatest possible effect, and thus contribute to the development of a healthy and robust Baltic Sea ecosystem.

Eutrophication is the problem: A new report from HELCOM of October 2021 stated [1] that "Eutrophication remains the major environmental threat to the Baltic Sea. It results in intense algal growth and depletion of oxygen on the bottom of the sea, further leading to vast areas with anoxic or hypoxic conditions in the Baltic Sea and affects the entire ecosystem" [1]. The reason is "…an excessive input of nutrients - phosphorus and nitrogen - to the aquatic environment" [1].

A number of different international regulations and agreements aim at combating the environmental impact of the overload of nutrients to the Baltic Sea. In particular, the following activities are to be mentioned:

- (a) EU Water Framework Directive with the Third Action Period 2021-2027;
- (b) Marine Strategy Directive with an Action Period 3 from 2021;
- (c) the sea oriented Natura 2000 areas (Birds and Habitats Directives) with specific efforts to protect and restore the ecosystems in the selected areas;
- (d) Activities of the HELCOM Convention with the specific focus on the new updated Baltic Sea Action Plan [2].

In the further course of this chapter, the focus is on the following two regulations: EU Water Framework Directive (the Third Action Period 2021-2027) and the new updated Baltic Sea Action Plan from HELCOM.

1.1. Approach of the EU Water Framework Directive

The Water Framework Directive [3] focuses on all types of water, hence including coastal and sea water. There are two important elements of the Water Framework Directive, namely the focus on ***continuous improvements*** and the focus on water districts or ***river basin districts***. River basin districts consist of the spatial catchment area of the river as a natural geographical and hydrological unit. Thus, the areas are not divided according to administrative or political boundaries, but according to the related natural geographical and hydrological areas.

The implementation of the Water Framework Directive takes place within the framework of the ***Common Implementation Strategy***. Within the specific catchment areas, a number of targets are set, e.g. the reduction of nitrogen emissions to the aquatic environment. The current status is described and the need for action in the coming period is determined. The effort is divided into a number of phases, of which we are now in the third phase, which started at the end of 2021 and is running to the end of year 2027. The main elements of this approach are illustrated in Figure 1 below.

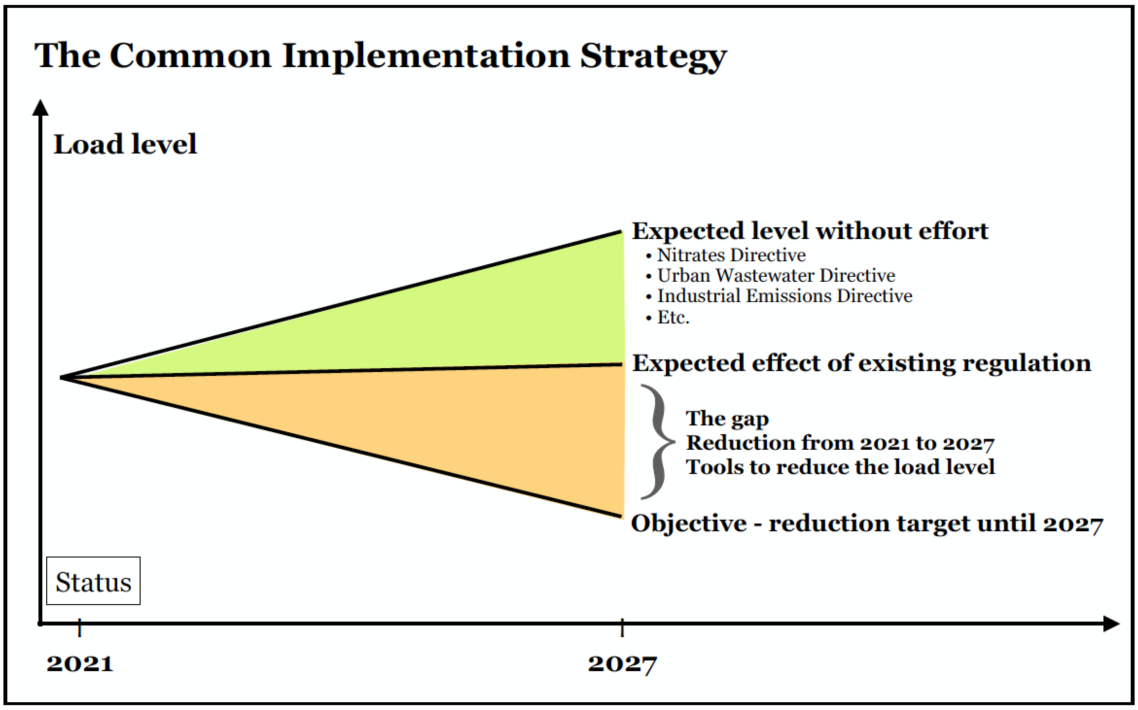

Figure 1: Common implementation strategy, illustrated for the period 2021-27, with target for the nu-trients load at the end of the period (2027). [4]

The starting point is the improvement of the state of the aquatic environment over the current intervention period (2021-2027). In principle, three evaluations are made: ***First***, the expected load is estimated if nothing is done (the so-called frozen policy). The idea is that the Water Framework Directive should not replace already existing regulations, but should supplement the already existing regulations and efforts. It is therefore important to have a picture of the results that can be expected from the various existing regulations that are relevant to the area.

The ***second*** estimate is about the expected effect of existing regulations. How large a reduction can be expected from the various regulations (nitrates directive, urban wastewater directive, etc.) in the intervention period. This is important for the factors that affect the area's environmental condition, e.g. the amount of nitrogen emitted or the change in emission of nitrogen in the given catchment area, and thereby affecting the eutrophication in the sea area. The most important points here are the emission of nitrogen and phosphorus from the catchment area to the surrounding sea areas.

The ***third*** point in the Common Implementation Strategy is the setting of a target for the sea area for the intervention period that lasts until 2027. The setting of this target shows a gap between the expected level of development (the second estimate) and the target level.

In order to cover the gap, an overview is made of the various ***instruments or tools*** that can contribute to the fulfilment of the set objective. Collecting and using cast seaweed in a biogas plant is a fairly effective instrument or tool. This will be illustrated in more detail with concrete figures for the intervention period 2021-2027 in Køge Bay catchment area as shown in Figure 2:

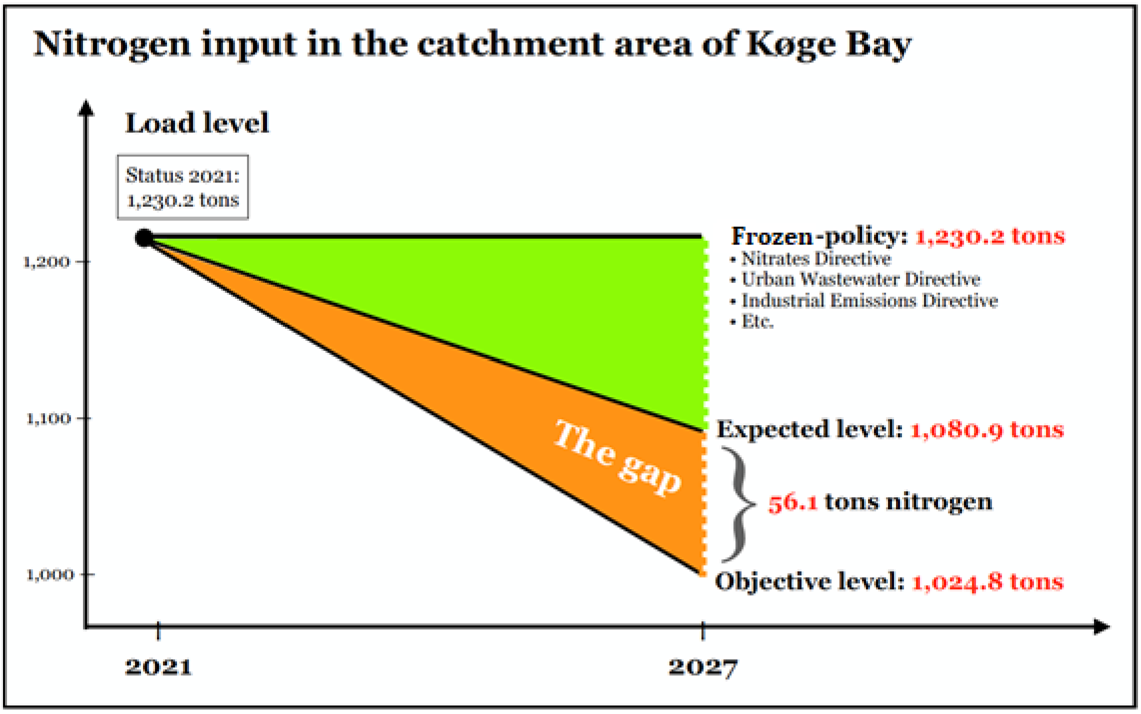

Figure 2: Common implementation strategy, illustrated with the nitrogen load in the catchment area of Køge Bay. Yearly nitrogen emissions [5]

Figure 2 shows the three elements as part of the common implementation strategy. ***Firstly***, the nitrogen load level of 1,230.2 tonnes at the end of the previous intervention period (2012-2021), where it is assumed that this level – without regulation – will remain at the same level after the end of the third intervention period at the end of year 2027.

Secondly, the figure shows the estimated level of nitrogen emissions as a result of the effects of the different already existing regulations (nitrates directive, urban wastewater directive, industrial emissions directive, etc.). By the end of 2027, nitrogen emissions are expected to amount to 1,080.9 tonnes.

The ***third*** step is the target level, which is estimated to be ***1,024.8 tonnes*** of annual emissions of nitrogen. This objective reflects the overall national objective, and reflects the overall reduction objective and its distribution on different Danish coastal waters.

The figure shows a gap of ***56.1 tonnes*** of nitrogen between the expected level and the target level. In the Køge Bay catchment area, an annual reduction of 56.1 tonnes must thus be achieved. A number of instruments are linked to agriculture as the largest contributor to nitrogen emissions. The instruments can comprise, among others, an extensification of agriculture (e.g. organic farming), reduction of the agricultural area by afforestation, establishment of lowland areas, etc. These measures would be achieved by reducing agricultural production and yield. A supplement or alternative to this is the collection and utilisation of cast seaweed in biogas plants.

Not all coastal areas in the Baltic Sea are similar to the conditions in Køge Bay. However, it is expected that in most of the catchment areas, it will be relevant to use the methodology contained in the common implementation strategy of the Water Framework Directive common implementation strategy, which is illustrated in Figure 3.

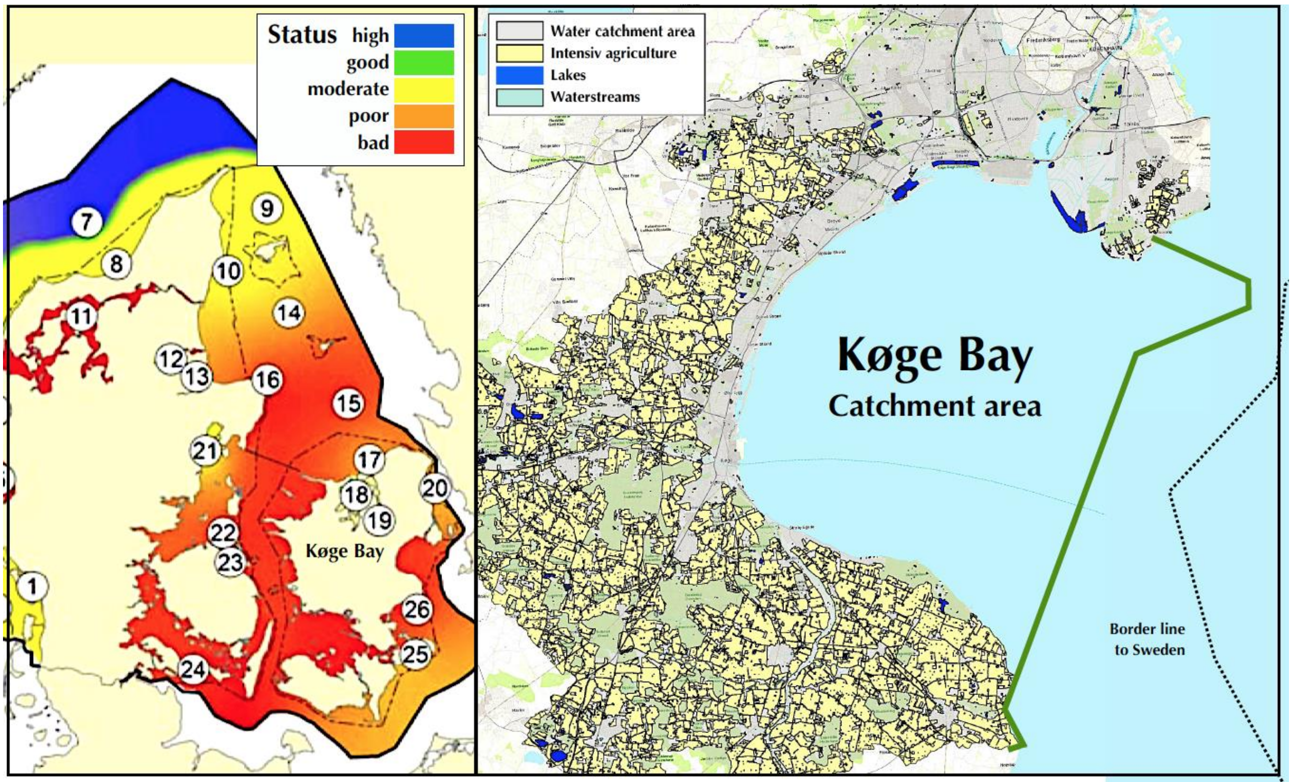

Figure 3: State of eutrophication in Denmark and the delimitation of the Køge Bay catchment area.

Reduction of eutrophication implies minimising its negative effects such as loss of biodiversity, deterioration of the ecosystem, harmful algae blooms and lack of oxygen on the seabed. The conditions for using seaweed as a co-substrate in biogas plants depend on the amounts seaweed in the respective areas. There might be large variations between the different catchment areas, which must be taken into consideration.

1.2. Approach in HELCOM - updated Baltic Sea Action Plan

In October 2021, HELCOM presented an updated action plan for the Baltic Sea [6]. The plan focuses on four issues: (1) Biodiversity, with its goal of a healthy and resilient Baltic Sea ecosystem; (2) Eutrophication, with its goal of a Baltic Sea that is unaffected by eutrophication; (3) Hazardous substances and litter, with its goal of a Baltic Sea that is unaffected by hazardous substances and litter; (4) Sea-based activities, with its goal of environmentally sustainable sea-based activities.

The HELCOM report points to four themes that can contribute to a reduction in nutrient load, cf. the objective of reducing eutrophication [7]:

- ***First theme:*** Agriculture with 14 specific efforts and action plans that focus on all aspects of nutrient load from agriculture.

- ***Second theme:*** Atmospheric nitrogen emissions with three specific efforts, where it is mainly about reduction of agricultural ammonia emissions.
- ***Third theme:*** The waste water section with seven specific efforts and action plans.
- ***Fourth theme:*** Nutrient recycling also with seven specific efforts and action plans. The fourth theme is particularly relevant in this context. The main focus is on nutrient recycling, which is also linked to a recycling strategy that HELCOM will develop towards 2027.

The Baltic Sea regional nutrient recycling strategy by 2027 has, among others, the following important elements:

- (1) Implement adequate measures to achieve the objectives of the Baltic Sea regional nutrient recycling strategy by 2027.
- (2) Create legal and institutional tools to reduce nutrient surplus.
- (3) Enhance the use of recycled nutrients in agriculture making use of the best available technologies and fertilise according to crop needs.
- (4) Improve the conditions for the development of a market for recycled fertiliser products by setting incentives with the aim of making the use of such products equally attractive to farmers as the use of mineral fertilisers.

Eutrophication remains to be the major environmental threat to the Baltic Sea. Over 96% of the region is characterised as being a below good status with regard to eutrophication. The input of nutrients originates from natural sources and from various human activities on land and at sea. In recent years, more than 800,000 tonnes nitrogen and 25,000 tonnes phosphorus have entered the Baltic Sea annually [8]. Eutrophication results in intense algal growth and depletion of oxygen on the bottom of the sea, which further leads to vast areas with anoxic or hypoxic conditions and affects the entire ecosystem.

To gain a healthy aquatic environment in the Baltic Sea, HELCOM has set up an annually maximum allowable input (MAI) for nitrogen and phosphorus. The MAI for nitrogen is 800,000 tonnes and 20,000 tonnes for phosphorus per year. As indicated in Figure 4 below, the total input of nitrogen and phosphorus are above the maximum allowable input levels [9].

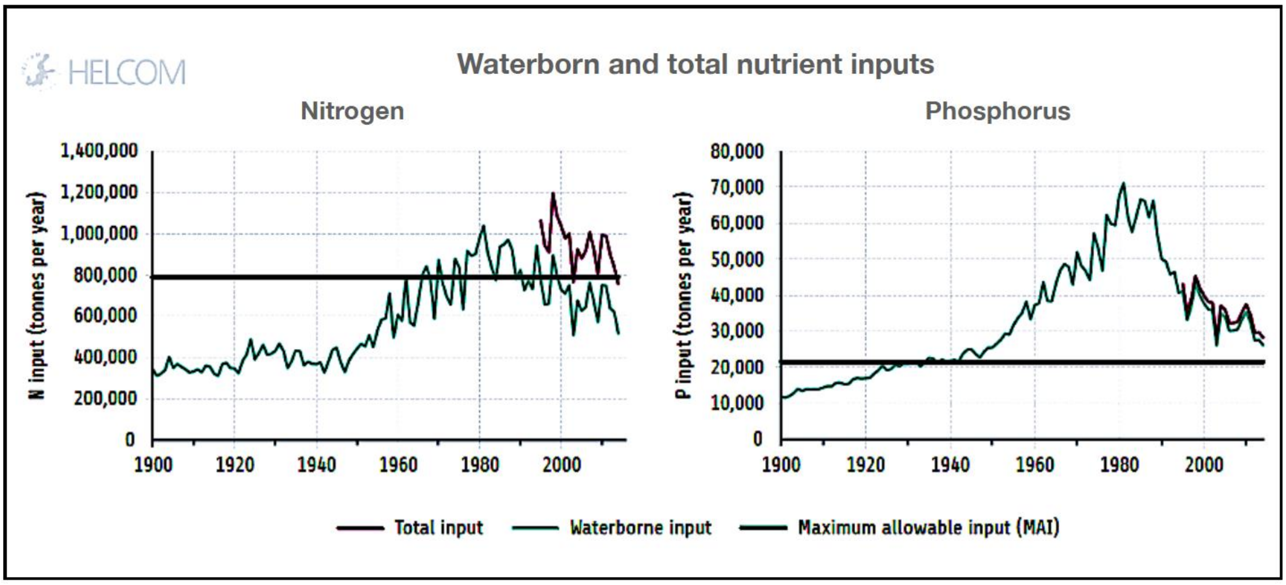

Figure 4: The total input of nitrogen and phosphorus to the Baltic Sea in the period 1900-2016 with indication of the maximum allowable nitrogen and phosphorus emissions [10]

To ensure that the input to the Baltic Sea does not exceed the maximum allowable input level, HELCOM has divided the annual total inputs of nutrients to the Baltic Sea subbasins with targets for each of the subregions in the Baltic Sea. See Figure 5 below [11]. Further reductions of the input of nutrients to the Baltic Sea are required.

Maximum allowable inputs • MAI

Area	Nitrogen in tons/year	Phosphorus in tons/year
Kattegat	74,000	1,687
Danish Straits	65,998	1,601
Baltic Proper	325,000	7,360
Bothnian Sea	79,372	2,773
Bothnian Bay	57,622	2,675
Gulf of Riga	88,417	2,020
Gulf of Finland	101,800	3,600
Baltic Sea	**792,209**	**21,716**

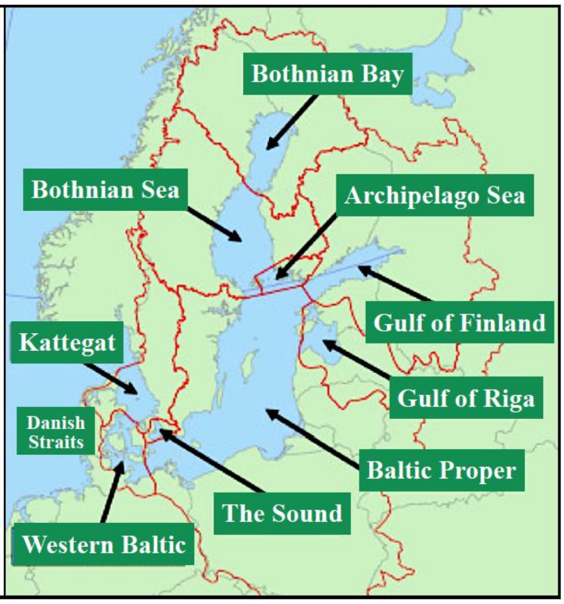

Figure 5: The maximum allowable emission of nitrogen and phosphorus to Baltic Sea divided into water the regional districts [11].

1.3. Summary of Water Framework and the HELCOM approach

The main focus of the Water Framework Directive can be characterised as a continuous improvement strategy, which aims to achieve increased protection and improvement of the aquatic environment, for instance through a progressive (sustained) reduction in emissions.

The common implementation strategy prescribes (a) determination of the actual status, (b) determination of intervention targets, followed by (c) determination of the gap or improvement requirements to be covered during the intervention period (2021-2027). For this implementation strategy it becomes crucial to have sufficiently effective tools or instruments available.

An important element of the HELCOM action plan is the Baltic Sea regional nutrient recycling strategy. The strategy focuses on the large emission of nutrients, both the environmental impact that losses represent, but also the economic inadequacy represented by the emission and the losses of nutrients.

There are three important elements in the mentioned nutrient recycling strategy:

- (a) It is required to limit the loss of nutrients through what is known as precision farming.
- (b) Secondly, methods for recycling the nutrients must be developed. There are many pathways, but an important way is to work with biogenic nutrients rather than artificially produced fertilisers.
- (c) The third element is to create a demand for recycled nutrients, which of course requires that they do not contain harmful substances (e.g. heavy metals).

2. The benefit of the collection and use of seaweed

The collection of seaweed and the use of the collected material in a biogas plant could be an answer to the issues raised in the common implementation strategy of the Water Framework Directive and by the Baltic Sea regional nutrient recycling strategy. The effect of the collection and use of seaweed in biogas plants is depicted in Figure 6.

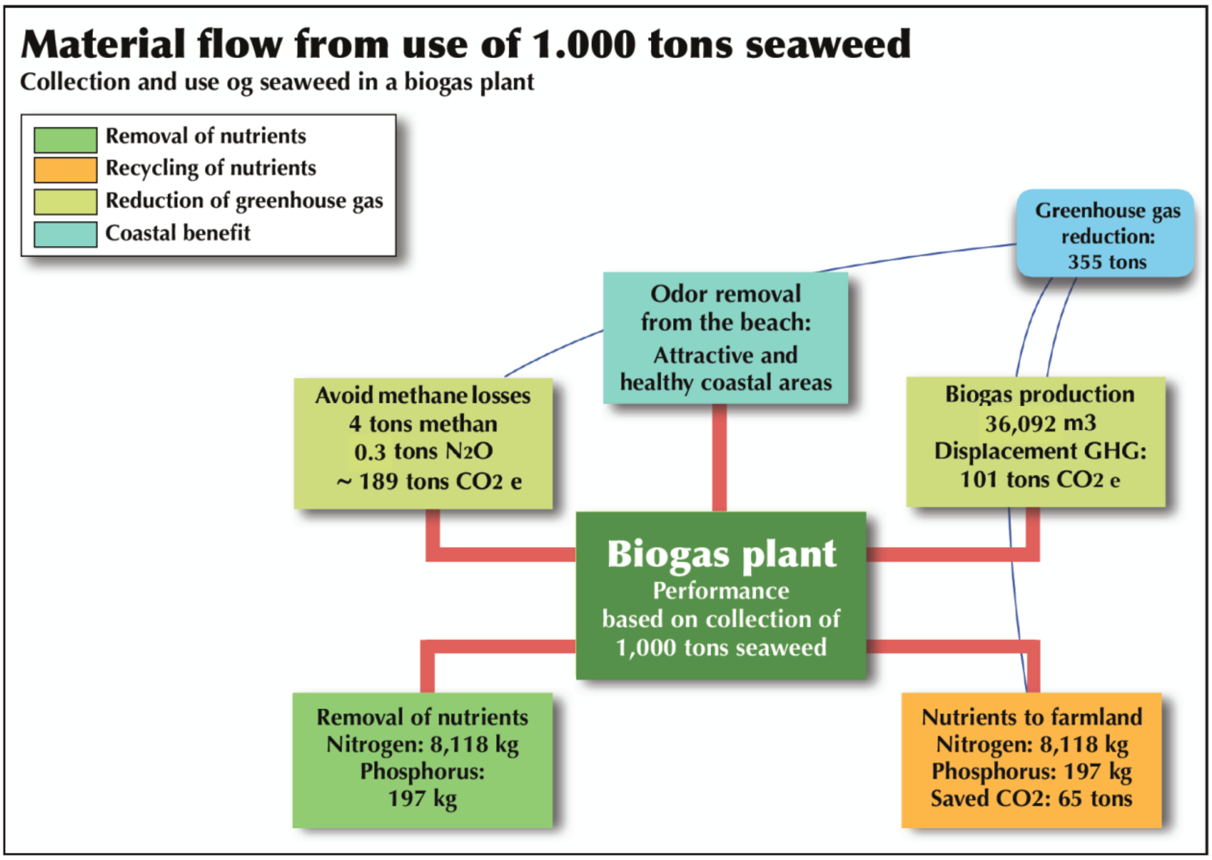

Figure 6: The material flow from collecting and using of 1,000 tonnes seaweed in a biogas plant, based on dry matter content on 30% [12].

The figure shows that there are ***multifunctional*** effects of using cast seaweed as a co-substrate in biogas plants. The main elements are the following:

- ***Removal of nutrients:*** Collecting seaweed removes the nitrogen and phosphorus that will be released to the marine environment as the seaweed decomposes in the sea or on the beach. When collecting 1,000 tonnes of seaweed, the calculations show that 8,118 kg of nitrogen and 197 kg of phosphorus can be removed. The figures vary according to seaweed and collection conditions.
- ***Recycling of nutrients:*** The nutrients that are removed with seaweed can subsequently be recycled as biobased nutrients. An important issue is that the nutrients can be provided without accompanying undesirable substances such as heavy metals (cadmium) or plastics. By recycling the nutrients, it would be possible to save greenhouse gases emitted by the nitrogen production process. The nutrient recycling would support the Baltic Sea Regional Nutrient Recycling Strategy.
- ***Reduction of greenhouse gases:*** The total greenhouse gas reduction is calculated to amount to 355 tonnes of CO_2 equivalents when using 1,000 tonnes of seaweed. A reduction of 65 tonnes is achieved by replacing fossil nutrients with biobased nutrients. This climate benefit supports the reduction requirement by the United Nation Framework Convention on Climate Change (UNFCCC) and the EU climate action requirements.
- ***Coastal benefit:*** Degraded seaweed on the beach and at the water's edge is a major nuisance to both humans and animals. In a number of cases, seaweed decomposes into an impermeable

muddy mass, which is both smelling and highly annoying to coastal and seabirds, etc. It would be an advantage to remove the seaweed that has ended up near the coast or on the beach [13].

The composition of the collected seaweed has an impact on the biogas yield. Some of the most important variations are indicated in Table 1 below [14].

Table 1: Variation of the standard figures [14].

Collection of seaweed	
Dry matter content of seaweed	Variation: 12-54%. The calculation in Figure 6 is based on a dry matter content of 30%.
Nitrogen content	8,118 kg per 1,000 tonnes seaweed. Variation: 4.8 to 30.0 kg/t dry matter
Removal of phosphorus	197 kg per 1,000 tonnes seaweed. Variation: 0.6 to 1.5 kg/t dry matter
Avoided greenhouse gas loss per 1,000 tonnes seaweed	4 tonnes methane and 0,3 tonnes N_2O, equal to a greenhouse gas reduction of 189 tonnes CO_2 equivalents
Use of seaweed in biogas plants and recycling of nutrients	
Production of biogas	36,092 m^3 per 1,000 tonnes seaweed, depending on how fresh the seaweed is. A typical variation between 54-150 m^3/t dry matter. On the beach, dried up around 54 m^3; collected close to the coast around 120 m^3; fresh and directly from the growth area around 120-150 m^3/t dry matter.
Nutrients recycling	8,118 kg nitrogen and 197 kg phosphorus per 1,000 tonnes seaweed. Dried out materials at the beach have 2-4 kg nitrogen per tonne dry matter; the beach edge has around 8 kg nitrogen per tonne dry matter.

In order to keep the tool or instruments simple, it is recommended to use fixed values for the nitrogen and phosphorus contents, the biogas yield, etc. It is recommended to start by determining the expected dry matter content of the collected seaweed. If the dry matter content is known, it is possible to calculate the nutrient recycling, gas yield, etc., on the basis of the factors as listed in Table 1.

A small calculation example might be helpful. As previously mentioned, Køge Bay will have a nitrogen gap of 56.1 tonnes in 2027 compared to the starting point at the end of 2021 (see Figure 2). The nitrogen content per tonne of seaweed is estimated to 8,118 kg for 1,000 tonnes of seaweed (see Figure 6). This implies that the gap of 56.1 tonnes can be covered by an annual collection of 6,910 tonnes of seaweed in Køge Bay.

2.1. Collection of seaweed and the environmental aspects

The purpose of using the tool "collection and use of seaweed in biogas plants" is to achieve the greatest possible environmental benefit, not least taking into account the sea and its ecosystems. The factors mentioned in Table 1 show that the benefits are higher if the seaweed is completely fresh. Fresh seaweed has not lost higher amounts of its methane potential and nutrients content yet. With completely fresh seaweed, more nutrients from the aquatic environment can be removed, more nitrogen and phosphorus recycled, and a greater climate benefit through a higher gas yield can be achieved. Nevertheless, it is also necessary to take into account the importance of seaweed plants for marine ecosystems.

The intention is not to suggest direct harvesting of seaweed. Most of the seaweed grows near the coast, but one must wait to collect the seaweed until wind and weather have torn the seaweed up and washed it ashore. This is illustrated in Figure 7 below.

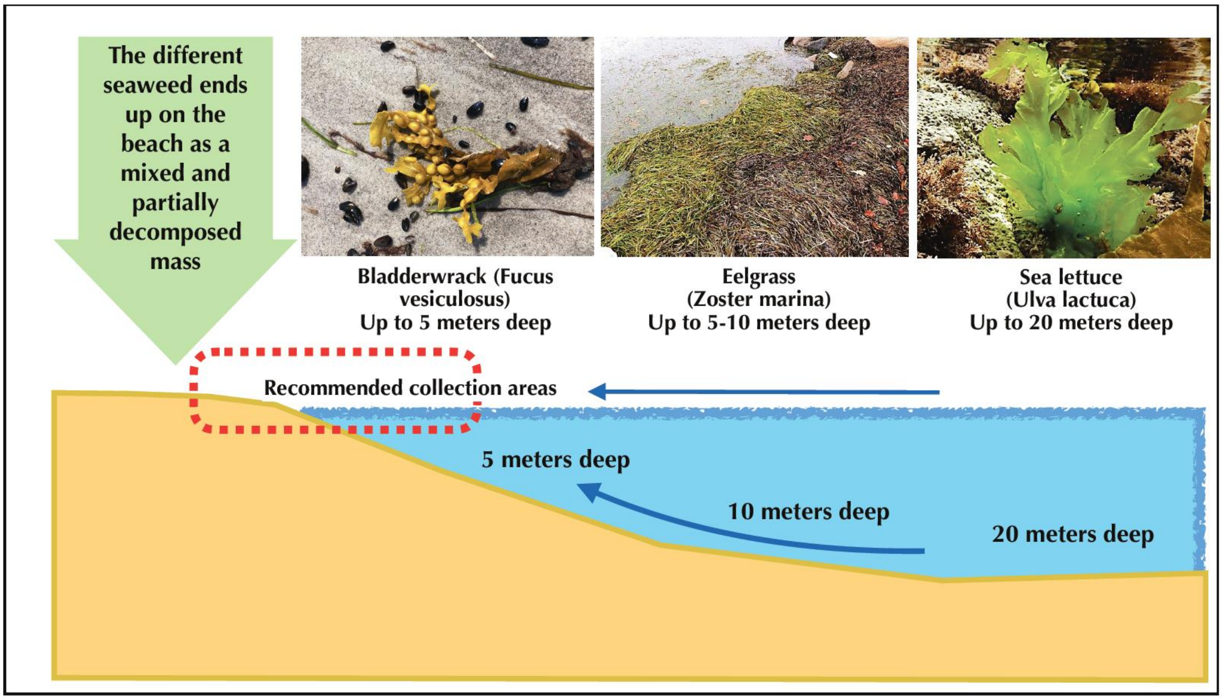

Figure 7: The life cycle of seaweed: From growth on the seabed to transport of wind and current to the coastal area.

When the seaweed is washed ashore, the degradation process starts, which can cause a decrease in methane yield in the biogas plant. Experiments at RUC have shown a decrease in the methane potential for seaweed, when seaweed is left on the beach for a longer period. The degradation process causes the decreasing methane potential [15].

It is worth noting that the coastal structure varies greatly in the Baltic Sea area. The sloping sandy bottom is the dominant coastal form, but not the only type of coastal landscape. At rocky coast areas, it is necessary to collect the seaweed in a different way than outlined in Figure 7 [16].

2.2. Using the tool - examples of the calculations of benefit

An important prerequisite for being able to use the proposed tool and its guidance is that the biogas plant operator is planning to establish a biogas plant in or nearby the coastal zone. If this condition is met, the next steps could be the following:

1) ***The amount of seaweed:*** How much seaweed can be collected – here and now and in the longer term? What is the expected dry matter content? If, for example, ***3,800 tonnes*** of seaweed can be collected, with an organic dry matter percentage of 30% (standard), the collection will correspond to 1,140 tonnes of organic mass.

Now you can use two different data sets; either the data in Table 1 (factors per organic dry matter) or the data in Figure 6, which are based on the entire amount of seaweed with a content of 30% dry matter content. It is easiest to use the numbers from Figure 6 as default.

2) ***Removal of nutrients*:** When collecting 3,800 tonnes of seaweed, 30.8 tonnes of nitrogen (8.118*3.8) and 749 kg of phosphorus (175*3.8) are removed.

Questions: How large will the effect on the nutrient load in the catchment area be? How big is the gap between the expected emissions and the expected reduction in the intervention period up to the year 2027? How much can the collection and removal of the nutrients contribute to the ecological situation?

3) ***Recycling of nutrients:*** The recycling will correspond to the nutrients that were removed, assuming that nutrients are not lost during collection, transport, fermentation and in the storage of the digestate. In the ideal case it is assumed that everything collected is utilised. This implies that there are 30.8 tonnes of nitrogen available together with 749 kg phosphorus.

The collected nitrogen replaces mineral fertiliser. It is assumed that the fertiliser is produced using fossil energy. If this is the case, a CO_2 emission of 8 kg per kg of fossil fertiliser is estimated. By collecting and recycling nitrogen from seaweed, an emission of 247 tonnes of CO_2 equivalents is saved (65 tonnes*3.8). There is also a CO_2 saving by recycling phosphorus, it is however difficult to estimate. Nevertheless, the recycling of phosphorus is deemed to be an important factor.

4) ***Reduction of greenhouse gasses***: The production of biogas has two significant effects. On the one hand, the formation of methane by the decomposition and rotting of seaweed in nature is avoided. Here, the gain is calculated at 718 tonnes of CO_2 equivalents from the reduction of methane and nitrous oxide (189*3.8). The produced biogas is used for the displacement of fossil energy sources (oil, coal, natural gas). Here the expected reduction is 384 tonnes (101*3.8).

The calculation example shows: In total, a reduction of greenhouse gases of 1,349 tonnes is achieved from the collection of 3,800 tonnes of seaweed, due to the removal/recycling of nutrients, from avoiding emissions from discarded organic material and from the production and use of biogas.

It is easy to quantify the benefits of collecting and using seaweed. One can hardly put numbers on the other benefits, those associated with contributions to reducing eutrophication and the benefits it provides at natural levels, such as clear water, a natural level of algal bloom, natural distribution and occurrence of plants and animals and natural oxygen levels.

3. Concluding remarks

A coastal biogas plant that gets some of its raw materials from the coast is deemed to be a very effective tool in the fight against eutrophication in the Baltic Sea region. Two regulatory measures can support this development, namely the EU Water Framework Directive and the updated Baltic Sea Action Plan from HELCOM. The former especially supports nutrient removal, and the latter supports nutrient recycling.

The effectiveness of the tool "coastal biogas plant" is based on the fact that it is possible to achieve multifunctional effects by establishing coastal biogas production. Plant operators get not only one positive effect from the effort, but also several simultaneous effects, which comprise the removal of nutrients from the sea area, recycling of nutrients, reduction of greenhouse gases and improvement of the coastal zone as a habitat for plants, animals and residents.

The development of the tool is based on the experiences gained in the project COASTAL Biogas concerning the collection and use of seaweed for energy production and the utilisation of the nutrients as a substitute to mineral fertilisers. It has provided a start on how the development and improvement of the nitrogen cycle and carbon cycle in conjunction with the blue resources can be driven forward.

4. References

[1] *Baltic Sea Action Plan. 2021 Update;* Baltic Marine Environment Protection (Helcom); *Helcom Extraordinary Minist. Meet.*, no. October 2021.

[2] *Baltic Sea Action Plan. 2021 Update,* op.cit. There are also other regulations that have consequences for the state of the sea, for example for example Nitrates Directive (agriculture regulation, relevance for nitrogen), Urban Wastewater Directive (relevance to nitrogen and phosphorus), Industrial Emissions Directive (relevant in special cases - especially waste water); Common Fisheries Policy and the Regional Fishery Convention ICES (nitrogen and phosphorus are a theme here) and Common Agriculture Policy (nitrogen and phosphorus are also a theme her).

[3] *EU Water Framework Directive* (WFD) was adopted in October 2000. In order to support the implementation of the Water Framework Directive, a total of 37 guides have been prepared, in particular Guidance Document No. 23: *Guidance Document on Eutrophication assessment in the context of European Water Policies*; Technical Report, European Communities, 2009.

[4] See the guidelines for the Water Framework Directive, for instance *Common Implementation Strategy for the Water Framework Directive* (2000/609/EC; Guidance document number 1. European Communities, 2003, p. 17. Report produced by Working Group 2.6. WATECO.

[5] The data are based on new suggestions for a new Danish Water Framework intervention 2021-2027 in: *Forslag til Vandområdeplaner 2021-2027.* Miljøministeriet/Departementet. December 2021, see Appendix 1.1. The suggestions are based on the Water Framework basis analysis: *Basis-analyse for vandområdeplaner 2021-2027;* Miljøstyrelsen. December 2019 (43 sider].

[6] *Baltic Sea Action Plan. 2021 Update,* op.cit, p. 6.

[7] *Baltic Sea Action Plan. 2021 Update,* op.cit, p. 24-26.

[8] *Baltic Sea Action Plan. 2021 Update,* op.cit, p. 26.

[9] L. Svendsen and B. G. Gustafsson, "Waterborne nitrogen and phosphorus inputs and water flow to the Baltic Sea Waterborne nitrogen and phosphorus inputs and water flow to the Baltic Sea 1995-2017," *HELCOM Balt. Sea Environ. Fact Sheet 2019*, no. September, 2019.

[10] Helcom, "State of the Baltic Sea," pp. 1–155, 2018, doi: 10.1016/j.gaitpost.2008.05.016.

[11] *Baltic Sea Action Plan. 2021 Update,* op.cit., see table 1, p. 22.

[12] The calculations in figure 6 are based on the following values: Seaweed dry matter on 30,1%; the biogas yield is estimated as 120 m3 per tonnes dry matter seaweed. The phosphorus amount is estimated at 0.654 kg per tonne of dry matter and the nitrogen as 27,0 kg per tonne of dry matter.

[13] Se Michelle D.Hansen & Tyge Kjær: A report on beach cleaning and pre-treatment of seaweed, Coastal Biogas, September, 2020.

[14] Based on a number of studies and results, which are documented in more detail in: Nanna Skov Larsen & Tyge Kjær: A Report on Enegy Recovery from Anaerobic Digestion; D.4.2.II, Coastal Biogas, December 2021, and: Nanna Skov Larsen & Tyge Kjær: Energy Recovery - Pre-Treatment & Co-digestion Synergies; D.4.3.II, Coastal Biogas, Dcember 2021.

[15] See also C. H. Vanegas and J. Bartlett: Green energy from marine algae: Biogas production and composition from the anaerobic digestion of Irish seaweed species. *Environ. Technol. (United Kingdom)*, vol. 34, no. 15, pp. 22.

[16] See the description of the coastlines in Michelle D.Hansen & Tyge Kjær: A report on beach cleaning and pre-treatment of seaweed, op.cit.

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