COASTAL BIOGAS

Cluster On Anaerobic digestion environmental Services and nuTrients removAL

A report on beach cleaning and pre-treatment of seaweed

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Preface

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Cover photo

Beach cleaning at Solrød Strand beach, Photo by Michelle Hansen, Roskilde University

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Summary

Seaweed collection: There are several reasons for collecting seaweed from our coastal areas. First, the loss of methane from the biodegradation of the seaweed is reduced. Second, the loss of the nutrients contained in the seaweed released by the biodegradation is avoided. Third, you avoid the strong stench that can occur during the biological decomposition of the seaweed.

If the seaweed is to be used in a biogas plant, it is important that the seaweed is collected as fresh as possible. This means greater gas yield; meaning a greater amount of nutrients are removed from our sea areas. It also implies that the collected seaweed will contain less sand compared to seaweed that has been lying on the beach for a long time.

The recommendation is therefore to collect cast seaweed as fresh as possible. If not collected immediately, it will imply loss of nutrients to the sea, reduced gas yield at the biogas plant, and the increased content of sand in the collected seaweed.

The eutrophication of the Baltic Sea: Every year, significant amounts of nitrogen and phosphorus are added to the sea areas. In recent years, more than 700,000 tons and more than 25,000 tons of phosphorus have been added annually to the Baltic Sea.

The negative cycle of eutrophication consists of: Starting with supply of nutrients (nitrogen and phosphorus), implying strong growth in biomass production, and leading oxygen deficiency. The result is the declining biodiversity in the sea water. Eutrophication occurs particularly in coastal areas, where the production and biological decomposition of seaweed plays a special role. A Danish study presented later in the report shows that seaweed production takes place very close to the coastline.

Seaweed and seaweed production are part of the negative cycle of eutrophication. Admittedly, the production of seaweed absorbs nutrients, but with the biological decomposition of seaweed, the nutrients are released again. It therefore makes sense to collect the seaweed, thereby breaking the negative cycle of coastal eutrophication.

Seaweed amounts and collecting techniques: The project has collected data from the various coastal areas in the five partner countries. It shows a very large variation of between 22 tons to 2,629 tons of seaweed per km of coastline. The quantities are smallest in Poland and largest in Sweden. Based on this collection pattern and on a number of geodata (wind, temperature, coastal type), the annual amount of seaweed is estimated. Quantities are only calculated for the coastal areas where collection can take place, i.e. sandy beaches excluding nature 2000 areas.

The total amount is estimated at 2.1 million tons, corresponding to an average of 272 tons per km of coastline. These quantities of seaweed are estimated to contain 1,947 tons of nitrogen and 293 tons of phosphorus.

Collecting techniques: A comparative analysis has been made of seven different collection techniques. Reports and experience suggest that a tractor with a grating bucket should generally be

preferred. This technique can be used to collect seaweed from shallow waters (up to 1 meter) and from the near shore sandy beach. This technique is estimated to be applicable to 70% of the coastal areas where seaweed can be collected. The other techniques can only be used to a lesser extent. Pontoon machines can be used to collect seaweed in port areas, which are only estimated to cover 5% of the total collection areas in the five partner countries

Sand separation techniques: Even with the most ideal collection methods and collection time, sand cannot be avoided in the seaweed. The sand content can be up to 76.8% of the total collected seaweed.

Most biogas plants have a sand trap due to the fact that sand can appear in cattle manure, because sand is used as bedding. Upon closer examination, the conclusion is that a sand trap is not sufficient enough to separate sand from the seaweed. The project has therefore worked with two possible techniques for reducing the sand content; namely a high-temperature washing process and a sand separator.

The analysis of a washing process with tap water at 52°C or above shows that it is possible to achieve a significant reduction of the sand content. The 52°C has been chosen because it is the process temperature in the Solrød Biogas plant, and because material from it could be used for pre-treatment of the seaweed.

The sand separator is a well-established technology. Data from the manufacturer indicate that the sand can be removed up to 99%. The assessment is, however, that the technology would be too expensive, unless sand also has to be removed from other raw materials used in the biogas plant.

Overall conclusion: Collecting seaweed should take place as soon as possible after it is washed up at the beach. The seaweed should be fresh, as it has a higher methane potential and the nutrients have not yet been released. The more fresh the seaweed is, the less sand it will contain. If the seaweed is collected when it is on a sandy beach, the seaweed should go through some sort of pre-treatment before entering the biogas plant. This pre-treatment can consist of a form of washing, as well as chopping of the seaweed.

1. Introduction to beach cleaning and development of biogas plants based on marine substrates in the South Baltic Area (SBA)

This report focuses on seaweed collection. The intention of the study is to help to enable the collection of seaweed with a minimum of sand content and a minimal impact on the coastal nature of the SBA. Assessment of treatment of seaweed for biogas digestion, including storage options, pre-treatment methods and optimal biomethane potentials. D4.1 contributes to the economic concept of WP5 and provides valuable operating concepts.

The further purpose is to contribute to the development of biogas plants based on marine substrates in the South Baltic Area.

The study has a special focus on investigation and documentation of collection techniques and pre-treatment to reduce the sand content and thus utilise the use of seaweed in co-digestion.

The study begins with a closer look at the seaweed quantities on the various sandy beaches in the SBA. There are a number of reasons to collect seaweed from beach areas, which include:

Collecting and removing cast seaweed can help to counteract eutrophication and improve the coastal water quality. When used in anaerobic digestion, the digestate can replace artificial fertilisers and contribute to biogas production.

There is no way to remove seaweed from beaches without also removing some percentage of sand. This means that the sand that is removed from the beaches is fed into the biogas plant. This affects both the nature and the biogas facility, since the pipes and moving parts are in risk of being worn out.

The purpose of this report is to provide a description of the different techniques suitable to collect seaweed with a minimal sand content, how to pre-treat and co-digest the seaweed so the nutrients and energy production are at their best, how to store the seaweed until digested and finally, what to do with the separated sand.

2. Why collect seaweed?

When collecting cast seaweed, it is possible to use the material for energy purposes. However, to generate energy from the seaweed, the material needs to be collected at the right time with the highest energy potential and with the right technique.

Seaweed on beaches degrades over time and loses some methane potential, which could be used in a biogas plant. Therefore, the seaweed needs to be collected as early as possible, preferably while it is just washed up at the beach or in the water. Besides the energy aspect of the collecting time, it is also important to use the right technique for collecting. The collecting of the seaweed should be done with no or as little harm as possible on the beach, and it should be done so that as little sand as possible is removed from the beach. This should be done so for the protecting of the beach itself but also for the biogas plant that can be damaged from the sand.

This chapter explains why the seaweed needs to be collected at the right time, when that time is specifically, where on the coastline the seaweed is best collected, as well as what to have in mind when collecting seaweed on the vulnerable and valuable coastlines.

2.1. Biomethane potential (BMP) and seaweed degradation

When collecting seaweed, the methane potential is also collected and removed from the coast. If not removed, chances are that the seaweed degrades and develop GHG emissions, e.g. CO_2 and CH_4. Depending on conditions, studies from Solrød show that the degradation of the seaweed can lead to emissions as high as 38.73 t CH_4 / t Wet Weight (WW) seaweed [1].

The development of methane at the coast is dependent on the conditions, meaning if the seaweed e.g. is laying in the water or is present at the beach in a thick layer, an anaerobic process can begin. If the seaweed is not at the beach under these conditions, CO_2 is released instead, which is estimated to be 1.84 t CO_2e / t WW seaweed [1].

Depending on the temperature, thickness of the wrack layer, and therefore the grade of aeration, and the moisture level etc., the seaweed should be collected before the degradation starts.

It should be considered if it is possible to collect the seaweed while still in the ocean, since it is only here that the sand content can be kept low (see chapter 5 Sand separation techniques), and where the degradation either has not started or is at a low stage.

The degradation of the cast seaweed is determined by the conditions mentioned above. Decomposition can happen either aerobic or anaerobic, and while the seaweed is still in the water. Temperature and "amount" also have influence on the decomposition. With "amount" meaning the height of the pile of seaweed, and the quantity. This is due to the fact that an anaerobic process can happen in the lower layer of a pile of seaweed. Furthermore, the species of the seaweed has a large effect on the time it takes for the seaweed to break down. Therefore, the seaweed should be collected as fast as possible, when the seaweed reaches the water near the longshore - see Figure 1: Beach profile (Copyright ©2010 Brooks/Cole, Cengage Learning).

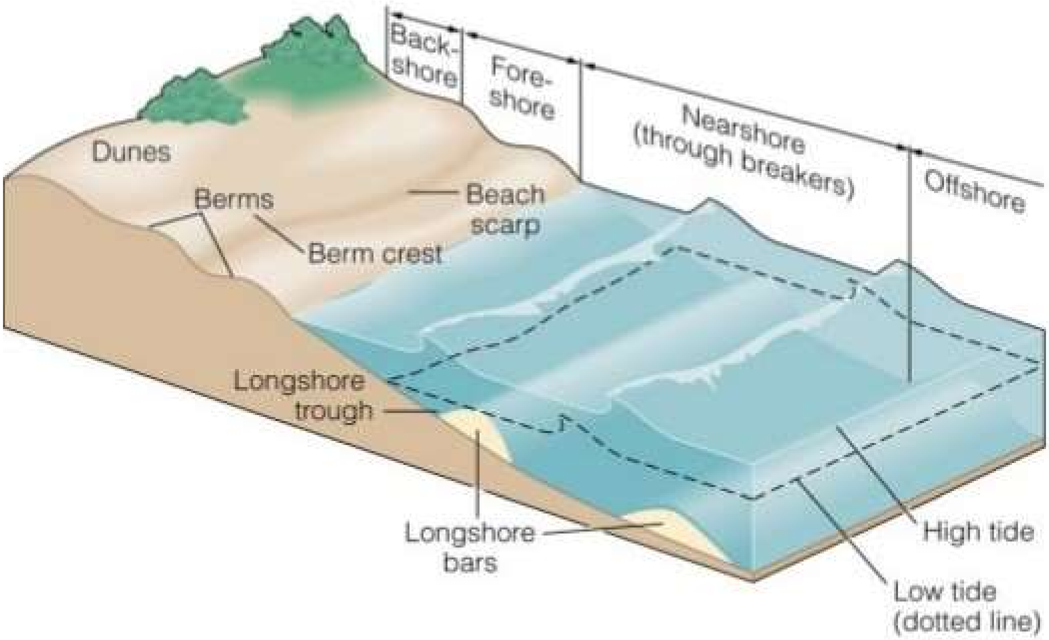


Figure 1: Beach profile (Copyright ©2010 Brooks/Cole, Cengage Learning)

When the decomposition of the algae has started, the biomethane potential (BMP) will decrease over time. The BMP for seaweed depends on the species. Studies from Roskilde University show that *Chorda filum* (dead man's rope) has a high BMP compared to ex. Pylaiella littoralis (303.99 vs. 71.07 [Nml CH_4/ g VS]). See Table 1 at the next page.

Table 1: Methane potential for different types of seaweed. VS, Volatile Solids

Types of algae	Methane potential ($Nml\ CH_4/g\ VS$)	Methane potential ($Nml\ CH_4/g$ algae)	VS (%)
Eelgrass (*Zostera marina*)	93.30	11.92	12.77%
Toothed wrack (*Fucus serratus)*	153.10	26.29	17.17%
Bladder wrack (Fucus vesiculosus)	107.86	18.65	17.29%
Dead man's rope/sea lace (*Chorda filum)*	303.99	16.40	5.39%
Sea felt (Pylaiella littoralis)	71.07	7.24	10.19%

Besides the study from Roskilde University, a study at Jacobs University in Bremen shows methane yields of some seaweed species (see Table 2).

Table 2: Methane yield of some seaweed species. VS, Volatile Solids [2]

Seaweed Species	Methane Yield ($mL \cdot g^{-1}$ VS)
Brown algae/knotted wrack *(Ascophyllum)*	110
Red algae *(Gracilaria)*	280–400
Kelp *(Laminaria sp.)*	180–300
Giant kelp/giant bladder kelp *(Macrocystis pyrifera)*	180–430
Gulfweed/brown algae *(Sargassum)*	120–190
Sea lettuce *(Ulva lactuca)*	200–480

In the case where the seaweed decomposed at the beach instead of being collected on time, the contained nutrients are released to the surrounding area – which is most likely the ocean. In Solrød it is estimated that the removal of the seaweed from the coast prevents 62 tons of nitrogen to be released into the water, and 7 tons of phosphorus [1]. At the same time, the methane potential of the marine biomass will drop over time. Depending on the conditions of the pile of seaweed on the beach, the gas released can be in the form of CO_2 or methane. To keep the nutrients and the methane potential in the seaweed, it must be collected as soon as possible. Besides the loss of nutrients and gas leaks from the rotting seaweed, the correct collection time and technique also effect the level of sand in the collected seaweed.

When the seaweed degradation starts, the methane potential is falling. This mean that even though the seaweed is collected, the gas potential is smaller compared to fresh seaweed. In addition to the potential release of greenhouse gasses (GHG), the nutrients are also lost. When this happens, the nutrients are washed out in the water, which has an influence on the nearshore sea environment, where the eutrophication has a high impact. The seaweed grows near the shores (see chapter 3 Eutrophication in the Baltic Sea), and the seaweed is then brought to the beach by the currents and waves. When the nutrients are released near the shore, it gives nourishment to the growth of more and new seaweed and microalgae. Besides this, the water will get muddied, the fishes will swim away and the smell of seaweed will worsen. The nutrients released in the coast near water will therefore contribute to a higher state of eutrophication in the area where the seaweed degrades.

2.2. Collection of cast seaweed on sandy beaches

When collecting the beach wrack, whether with machinery or by hand, some sand is removed with it from the beach.

Depending on the technique, e.g. raking or scraping, the sand content is up to 62% of the WW and 81% of the dry weight (DW) [3]. In Solrød Strand, where the seaweed is collected and about 50% of it is utilised at the biogas plant, the sand content is normally around 30% WW [4]. Around 1,500 tons of seaweed are collected in Solrød every year.

The sand content in the cast seaweed depends on how long it has been on the beach. Studies from Solrød show that new fresh cast seaweed and seaweed that still floats in the water have a much lower sand content than the seaweed that has been on the sandy beaches for a longer period of time. The older algae can have a sand content of up to around 32-77%, where the fresh seaweed contains as low as 14% when collected [5].

When using heavy machinery to clean the beach, the sand is compacted where the tracks are, but at the same time some surface sediments are loosened [3], which means that the surface sediments can be moved by the wind. The seaweed can therefore be covered by sand when it is on the beach. Furthermore, some types of algae are rooted in the bottom of the ocean floor, which means that it can drag the sand with it when it is loosened from the bottom e.g. during a storm.

When the tides change, the placement of the washed-up seaweed changes as well. If the seaweed is placed on the shore under the low tide period, it will be pushed further up the foreshore during the high tide. These pushes mean that the seaweed will be dragged over the sandy beach, and therefore contain more sand the higher up the foreshore it is placed. If the seaweed is already laying up on the top part of the foreshore, or higher on the beach, the changing tide can also mean that the sand is moved by the water and waves, and therefore can be placed on top of the already present seaweed.

Besides removing sand from the coastline, the removal of cast seaweed has some ecological impacts. The livelihoods for the intertidal biota are affected when the seaweed is removed, which then influences the shorebirds' feedstock. Further, the beach cleaning can disturb nesting shorebirds and spawning fishes [6].

When seaweed is laying on the beach degradation is a naturally occurring process. This causes odour, which is a nuisance for the residents and tourists staying near the beach. In addition to the smell, the degradation also causes air pollution.

However, it is important to stress that it is critical to respect and preserve protected areas, and cleaning of the beaches should therefore only happen when it is not disturbing and destroying the area.

2.3. Sand in the biogas plant

When sand is added to a biogas plant together with the marine biomass, it can cause some problems for the functioning of the plant. The sand will accumulate in the reactor over time and by this, the volume of the reactor will decrease. This leads to a lower biogas production. The sand must be removed manually and therefore, the plant needs to be shut down, which in Denmark costs around 13,300-20,000 EUR [7].

There are also other feedstocks that cause sand problems. One of them is cattle manure, which contains sand from the beddings in stables. When the manure is used as feedstock and contains high DM (dry matter) due to the sand bedding, it can lead to the sand replacing a quarter of the reactors volume over a six month period. In this case, the pumps and stirring mechanisms will be difficult to operate, the pipes will be clogged, and the biogas production will reduce. Therefore, it is essential to empty the reactor up to two times per year, which is costly. Furthermore, when the biogas plant is operating again it can take up to several months to restore an efficient and stable biogas production [7].

2.4. Concluding remarks

It is recommended to collect cast seaweed as fresh as possible. This is due to the loss in nutrients over time, the gas production that also evolves over time, and the increasing sand content. Studies from Solrød show that the sand content is lower in fresh new seaweed compared to seaweed which has been on the sandy beaches for a longer period of time. Furthermore, there are the aesthetic reasons as well as the bad odour.

However, there are a lot of positive effects when removing seaweed from the beaches. The positive effects include the removal of smell nuisance and bad odour, less air pollution and a cleaner aquatic environment. When the seaweed is removed, the nutrients and gas can be recycled via a biogas plant, and the environment and the beach will be improved due to the improvement of the water and air quality. The collection needs to be done in a way so that the flora and fauna are subject to a minimum of disturbance. At some places it may not be possible to avoid disturbance or even damages of habitats and in that case a collection of seaweed should not be carried out at least during some seasons.

3. Eutrophication in the Baltic Sea

According to Helcom *"at least 97% of the region was assessed to be below good eutrophication status, including all of the open sea area and 86% of the coastal waters"* where much of the eutrophication happens near the coastlines - see Figure 2. and Figure 3. The seaweed gets its nutrients near the coast, and if the degradation of the seaweed is not stopped, e.g. by collecting the seaweed from the beaches, the nutrients are released again near the coast.

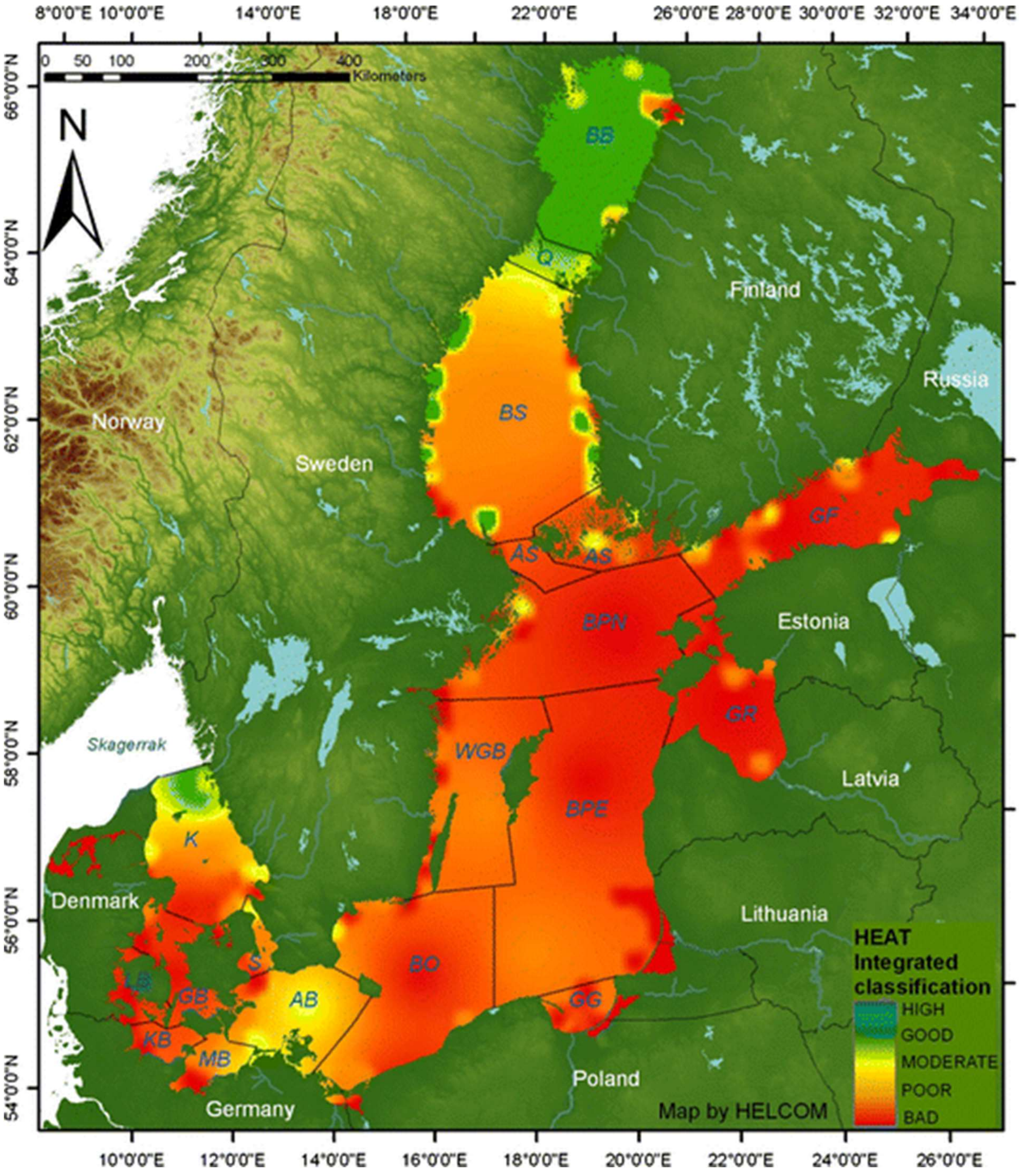


Figure 2: Five-class classification of eutrophication status in the Baltic Sea region, Map by HELCOM [8]**.**

In Denmark, the hydraulic institute, DHI, have mapped the marine vegetation for year 2018. This database is being expanded to cover several years. Figure 3 and Figure 4 depict where in Denmark most of the vegetation in the oceans occur.

Figure 3: Marine vegetation around Zealand, Denmark [18].

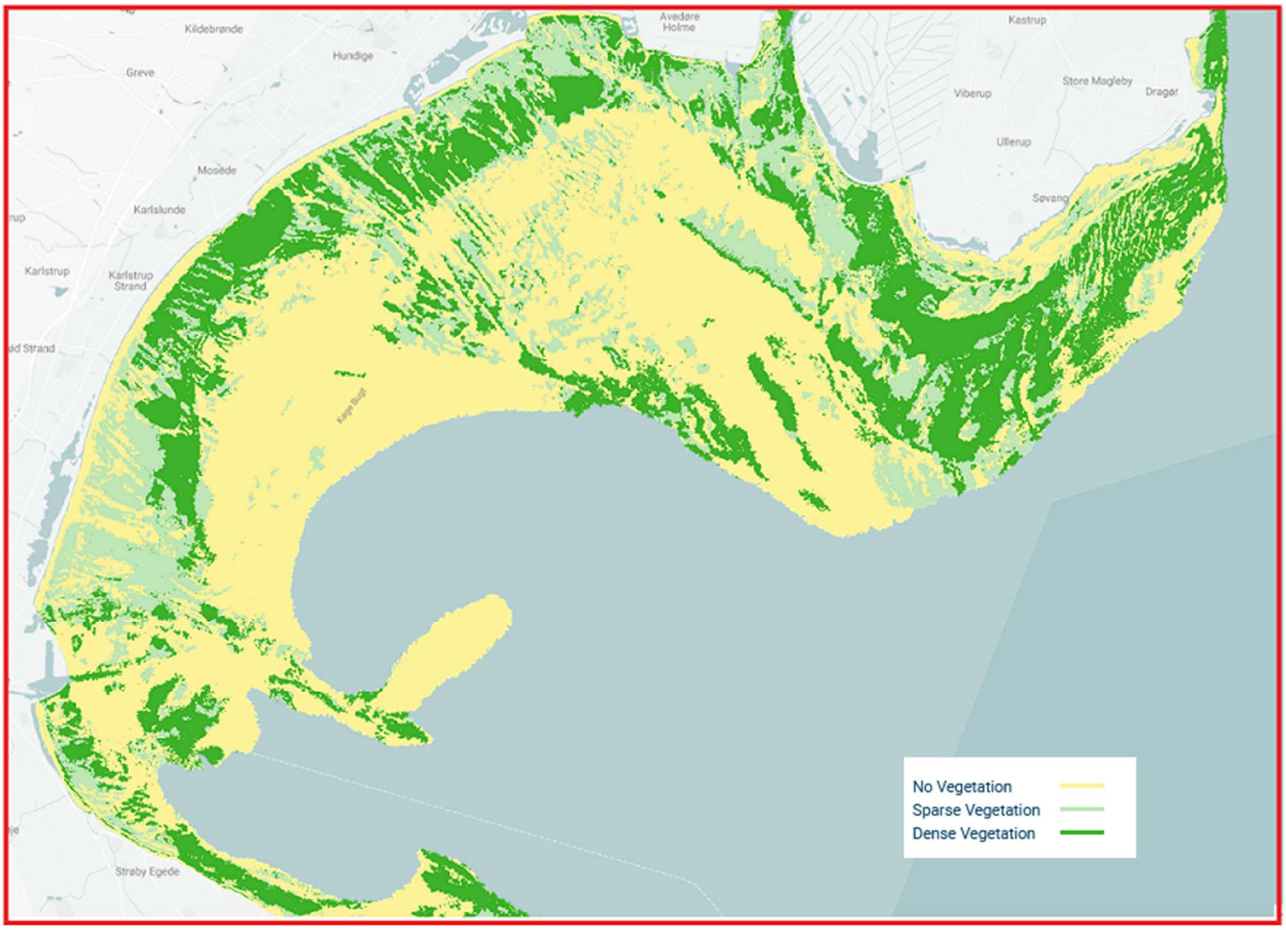


Figure 4: Marine vegetation in Køge Bay, Denmark [18]**.**

Both waterborne and airborne nutrients have an influence on the ocean's environment.

In agriculture, when a leaching of nutrients happens, the degree of the amount depends on the soil type, amount of water and precipitation – e.g. a rainy season will cause more leaching than a dry season. Further, the amount of present nutrients has an influence – more nitrate in the soil means more potential leaching.

Nutrients ends in the ocean via the so-called waterborne input. This means nutrients that are either leached to the water, e.g. the Baltic Sea, trough the diffuse source of input, or from a point source. 'Diffuse inputs' are the leached nutrients from the agriculture, storm overflows etc. The point sources are mainly waste water treatment plants and industries [10]. Besides the waterborne input to the Baltic Sea, the airborne plays a huge influence.

See Figure 5 of different sources of nutrients.

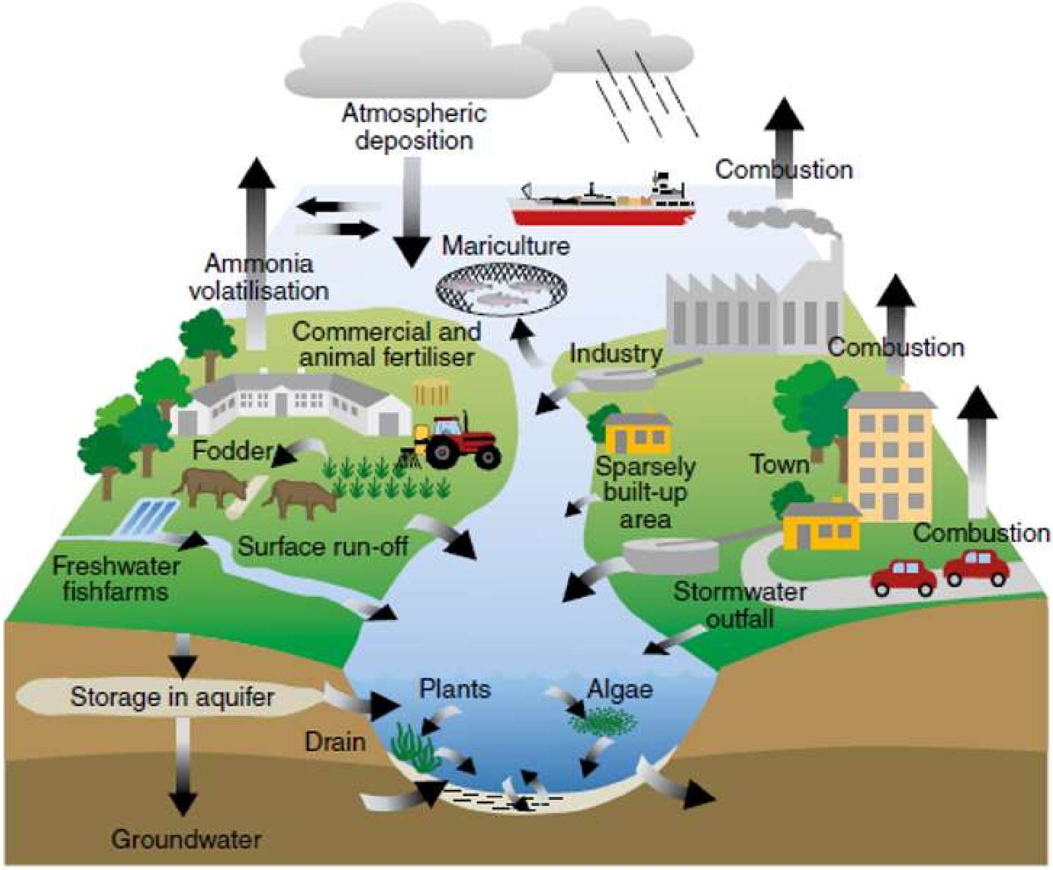


Figure 5: The nitrogen cycle and how it affects the coastal waters. Figure from Ærtebjerg et al. 2003 [11]

It is estimated that the airborne input of deposited nitrate in the Danish water in 2018 was 68,000 tons N. It corresponds to 6.4 kgN/ac., but the highest deposit happens near the coast where it is around 12 kgN/ac. [12].

Table 6 - Table 8 show the input of nutrients to the different sub basins in the Baltic Sea.

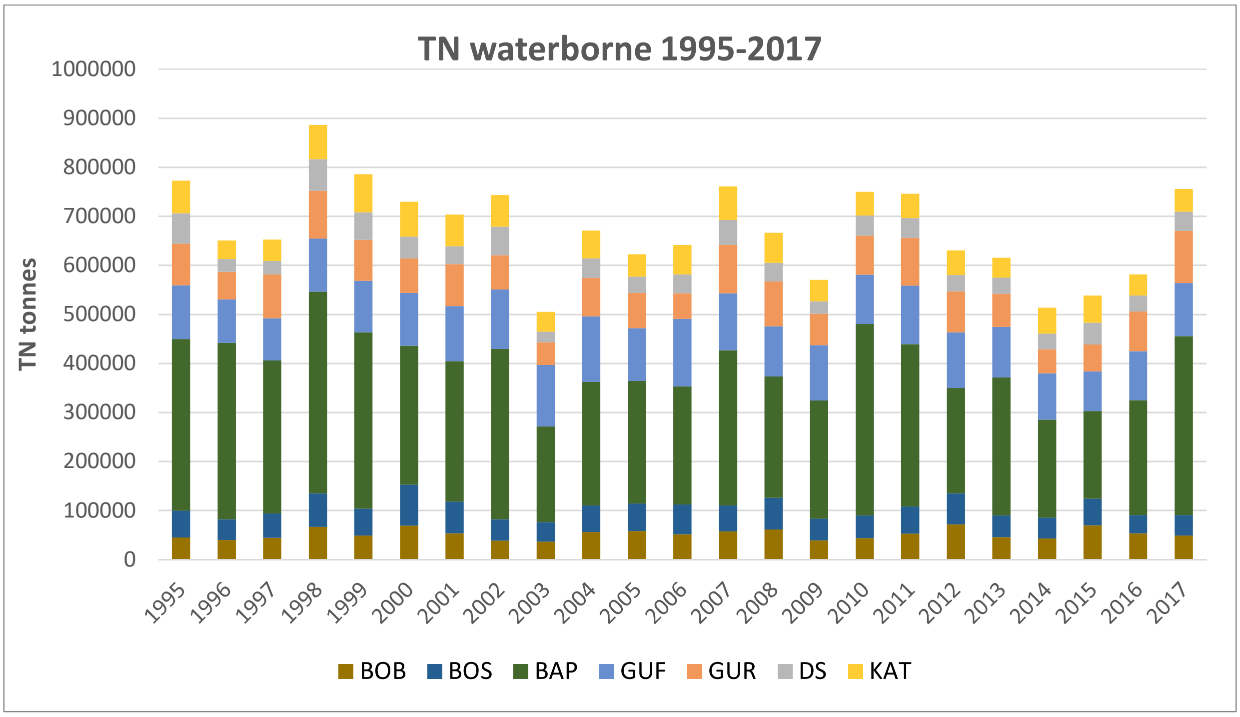


Figure 6: Total Nitrate (TN) waterborne 1995-2017[10]

Sub-division units of the Baltic Sea: the Kattegat (KAT), Belt Sea (BES), Western Baltic (WEB), Baltic Proper (BAP), Gulf of Riga (GUR), Gulf of Finland (GUF), Archipelago Sea (ARC) Bothnian Sea (BOS) and Bothnian Bay (BOB).

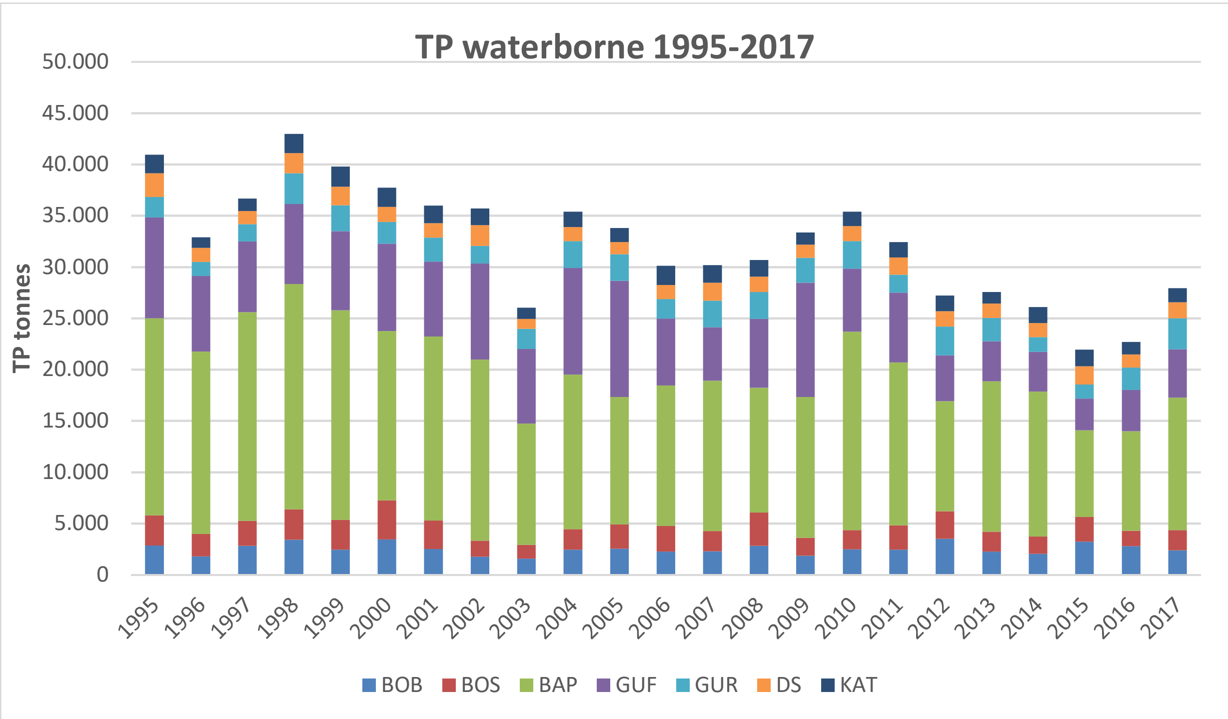


Figure 7: Total phosphor (TP) waterborne 1995-2017[10]

Sub-division units of the Baltic Sea: the Kattegat (KAT), Belt Sea (BES), Western Baltic (WEB), Baltic Proper (BAP), Gulf of Riga (GUR), Gulf of Finland (GUF), Archipelago Sea (ARC) Bothnian Sea (BOS) and Bothnian Bay (BOB).

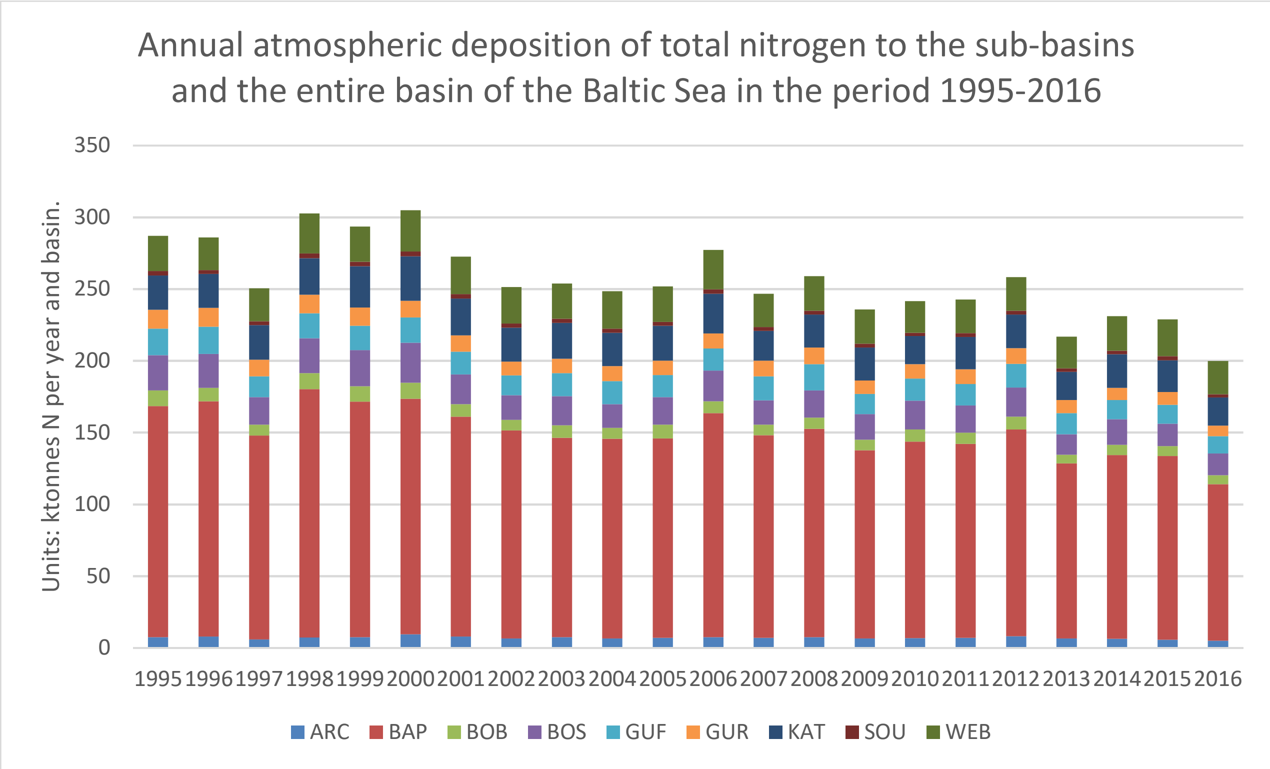


Figure 8: Annual atmospheric deposition of total nitrogen [13]

Sub-division units of the Baltic Sea: the Kattegat (KAT), Belt Sea (BES), Western Baltic (WEB), Baltic Proper (BAP), Gulf of Riga (GUR), Gulf of Finland (GUF), Archipelago Sea (ARC) Bothnian Sea (BOS) and Bothnian Bay (BOB).

In 2017, the waterborne inputs of total nitrogen (TN) was 12% higher than the average of 1995-2017, while the total phosphorous (TP) was 14% lower than the average [10] – see the following figure 9 for visualisation.

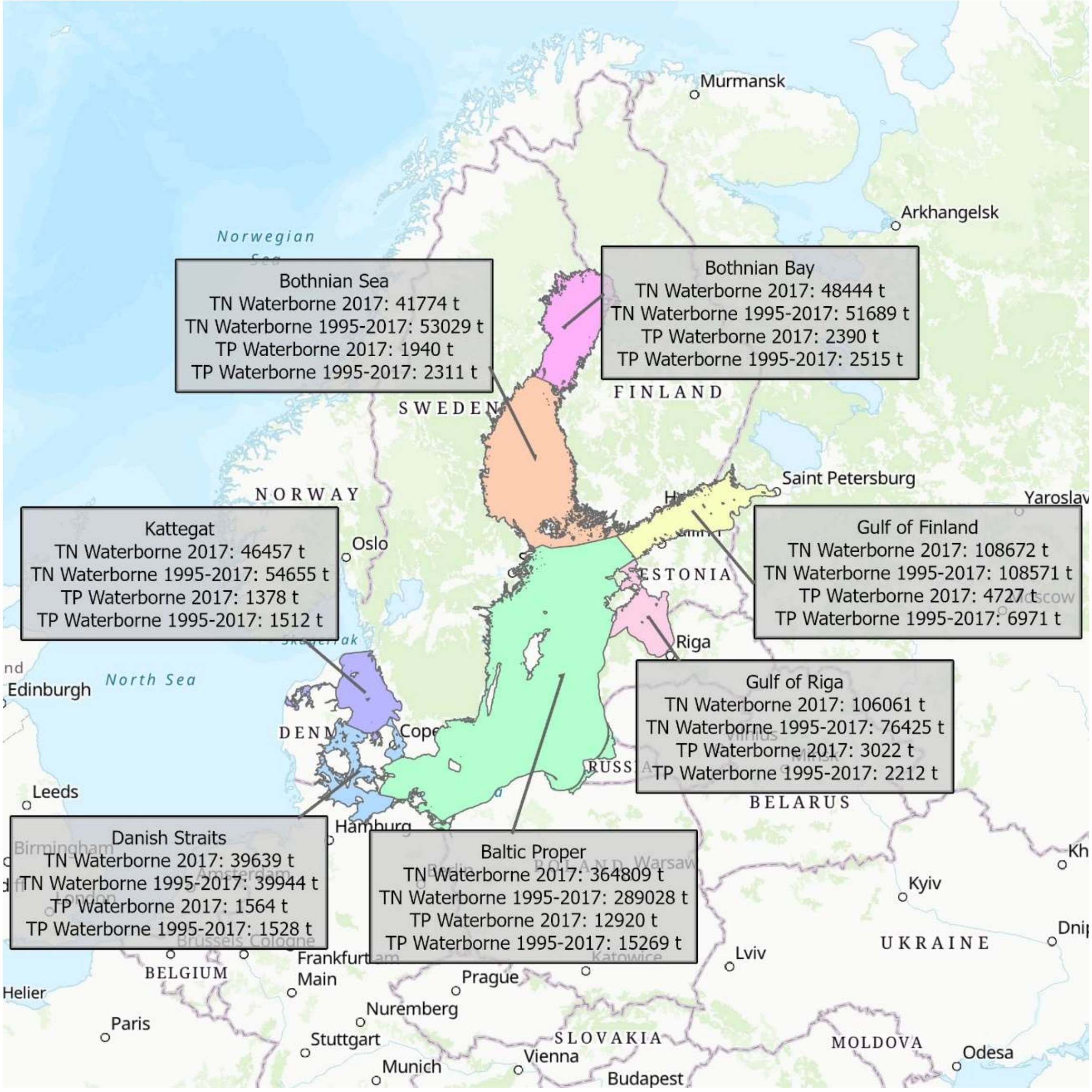


Figure 9: Sub basins in the South Baltic area and the HELCOM estimations of waterborne inputs (own illustration, data from HELCOM)

"Waterborne inputs enter the sea via riverine inputs and direct discharges. The main sources of waterborne inputs are diffuse sources (agriculture, managed forestry, scattered dwellings, storm overflows etc.), natural background sources, and point sources (as waste water treatment plants, industries and aquaculture). In addition, excess nutrients stored in bottom sediments can enter the water column and enhance primary production of plants" [10].

4. Seaweed amounts and collecting techniques

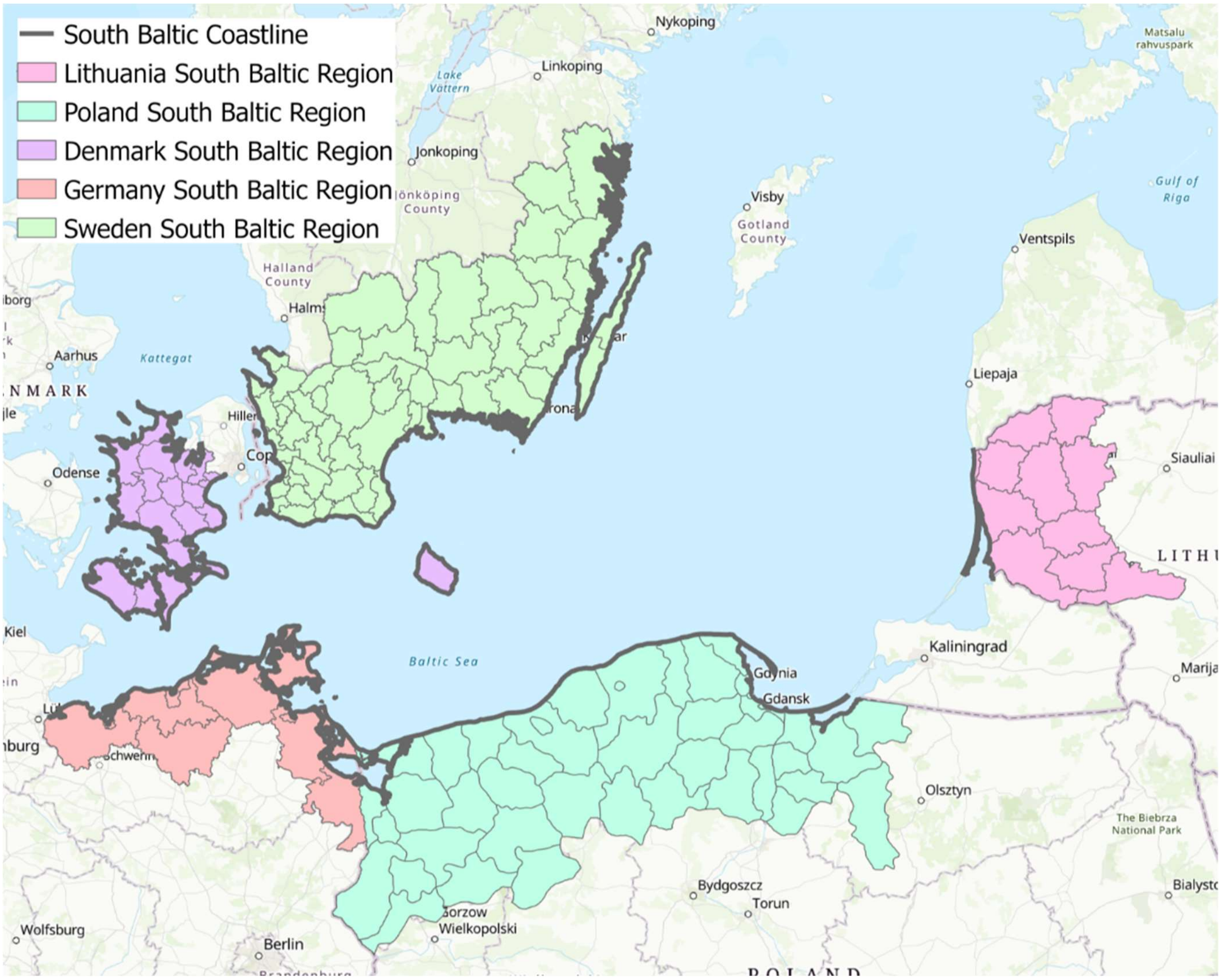


Figure 10: Map of the studied regions in the South Baltic area and their coastlines

This chapter describes the estimated and/or collected amounts of seaweed in the involved regions of the south Baltic (see Figure 10), and the techniques that are used for collecting the seaweed. Besides the factual amounts, Roskilde University have calculated the possible quantities that can be collected. These calculations are presented in the last section of this chapter.

4.1. Lithuania

In Lithuania, in the municipality of Palanga, seaweed is removed in the period from April to November. In the beginning of spring cleaning of the beaches is obligatory. However, it is noted that the largest amounts of seaweed are washed ashore during storms, regardless of the season. In the municipality of Neringa, the seaweed is removed from June to September and occasionally, when needed, while in the municipality of Klaipėda, the seaweed on the beaches is not collected.

A technique for removing seaweed in Lithuania is the use of the machine “BeachTech Marina”, which was purchased by the municipality of Palanga. The “BeachTech Marina” is a compact tractor and beach cleaner that can collect small to medium size debris, including seaweed, to a depth of 10 cm on the shore. In Palanga municipality, the gathered seaweed is transported to a green waste collection site, where it is composted together with other biodegradable waste. In the municipality of Neringa, the seaweed is transported to a composting site or a regional dumping site [14].

The amount of currently (2018) collected and potential seaweed in the municipality of Palanga is shown in Table 3.

Table 3: The current and possible amounts of seaweed in the municipality of Palanga

Municipality (km coastline)	Annual data (t/a)	Seaweed amount (t/km/a)		Coastline w/protected areas within ISBP (km)	Coastline without protected areas within ISBP (km)	Potential of seaweed (with protected areas) (t/a)		Potential of seaweed (without protected areas) areas (t/a)	
Palanga municipality (25 km)	50 [e]	min 2 [e] (2018)	max 400 [f] (2010)	95	27	190	38,000	54	10,800

[e] Data from Palanga municipality

[f] Unseen abundance of algae in Palanga beach [15].

According to data of Palanga municipality, 50 tons of seaweed were collected from the beach in 2018. An average amount of collected seaweed is 2 tons per km coastline during the recreational season. However, information found online states that in 2010 over 400 tons of seaweed was removed from about 1 km long beach section in Palanga [15].

4.2. Poland

The Polish coastline comprises the eastern and western part of the southern Baltic Proper and constitutes about 10% of the entire Baltic Sea [16]. The Polish coastline is 770 km long, where the major part of the coast is sandy beaches.

In Poland, the seaweed is usually removed in the period from May to October [16] during the tourist season. This happens even daily during the main tourist season (i.e. in August) on the biggest beaches of Gdansk Bay. The seaweed is mainly removed in shallow water with a grip-claw loader and a dumper and tractors equipped with harrows. Together with the waste it gets collected from the beaches and is transported to the nearest solid waste treatment plant, where the biomass is separated and composted (the information was obtained from the Department of Environmental Protection of Władysławowo Municipality).

In Poland, it is possible to collect seaweed from a perimeter coastline of 440 km length, when protected areas are not considered for collection. If the protected areas are considered, 770 km of coastline can be cleaned of seaweed, since all the beaches are sandy [16]. Because of the sandy beaches, it is possible for the machines to access the coast for collecting the seaweed.

Table 4 below shows the amounts of seaweed collected in Poland as well as the estimated potential of seaweed that is available for collecting with and without protected areas.

Table 4: The current amount of seaweed collected annually in Sopot, The Gulf of Gdansk and Poland.

Area	Annual collected amount of seaweed (t/a)	Seaweed amount (t/km/a)	Coastline including protected areas (km)	Coastline without protected areas (km)
Sopot (4.5 km)	400 (2011) [g]	100	770 [h]	440
Gulf of Gdansk (~150 km) [g]	13,000-50,000 [g]	86-333	770 [h]	440
Poland	-	22 [h]	770 [h]	440

[g] [17]

[h] Project Partner data (Poland)

According to City Sport and Recreation Centre (Gdańsk, Gdynia, Sopot), it is possible to collect 180 to 796 tons of fresh biomass from beaches and up to 700 tons (Department of City Cleaning in Sopot 2010) from the sea for the season. According to project partners, it is estimated that 9,500 tons of seaweed per year can be collected from the beaches of Poland. If the protected areas are considered in the calculation, it would be possible to collect 17,000 tons of seaweed per year, as is shown in table 4 above [16].

4.1. Germany

The German coast extends to over 3,600 km on both, the North and Baltic Sea. The length of the German Baltic Sea coast is 1,945 km and is characterised by steep coasts, beaches with fine sand, bays and fjords. More than half of the coastline belongs to the inner Bodden Coast, part of which consists of protected areas [16].

In Germany, seaweed is collected during the tourist season from May until September. Germany has 350 km of managed beaches. In some municipalities during the summer months, the beaches are cleaned every morning between 4 and 9 am before the tourists arrive. Other beaches are cleaned once or twice a week according to the cast seaweed amount.

In Germany, the collecting techniques vary in different municipalities. Most municipalities use wheel loaders or quad bikes/dune buggies to collect cast seaweed. The material is then transported to a short-term storage location, where the seaweed is composted and used as fertiliser or disposed at landfills [16].

On the German Baltic Sea coast, an average of 50 t of seaweed are collected per km per year. This gives a potential quantity of 17,500 tons of cast seaweed per year for the length of managed beaches (350 km) in Mecklenburg-Western Pomerania.

Table 5: The current and potential amount of cast seaweed on the beaches along the German Baltic Sea coast.

Scale	Annual data (t/a)	Seaweed amount (t/km/a)	Coastline with protected areas (km)	Coastline without protected areas (km)	Potential of seaweed (including protected areas) (t/a)	Potential of seaweed (without protected areas) (t/a)
Country managed beaches (350 km) [d]	17,500 [d]	50 [d]	377 [d]	306 [d]	18,850	15,300

[d] State parliament of Mecklenburg-Western Pomerania, 2017

Table 5 shows the annual amount of cast seaweed on the managed beaches along the German Baltic Sea coast and the potential amount of seaweed with and without protected areas.

4.2. Sweden

The total coastline of Scania is 440.101 km and includes fifteen municipalities (see Table 6). The removal of seaweed on the coast differs from beach to beach. The cleaning of seaweed takes place during the tourist season, which is considered to begin in the middle of May and ends in mid-September. During this period some beaches are cleaned daily while others are cleaned only a couple of times during the tourist season [16]. The quantities of seaweed removed from the beaches depend on the municipality, where some municipalities perform seaweed collection more often than others [18].

The most common way to remove seaweed from the Swedish coast is by heavy machinery. A Swedish study (Biogaspotential från akvatiska substrat i Skåne[1]) has examined beaches in the municipalities of Scania, with the purpose to conclude where it will be possible to clear the coastline of seaweed, based on the type of beach [18]. The study concluded that the removal of seaweed would be possible in the areas which consist of sandy beaches, as machines will be able to access these areas. The beaches with meadows towards the waterline, cliffs, big stones and hardly accessible beaches, were evaluated as not suitable for seaweed removal.

By examining all the coasts in the municipalities, it was possible to predict the average annual seaweed amount available for collection on the coasts of Scania. Table 6 shows the amount of seaweed that is currently being collected on average per year (recorded in the year 2014). The table does not include seaweed amounts from sandy beaches placed in nature reserves.

[1] https://utveckling.skane.se/publikationer/rapporter-analyser-och-prognoser/biogaspotential-fran-akvatiska-substrat-i-skane/

Table 6: The current and the possible amounts of seaweed in the municipalities of Scania [18]

Municipality	Total coastline (m)	Sand beach (m)	Cleared seaweed per km (t/km/a)	Current amount of cleared seaweed (t/a)	Possible amount of seaweed per km (t/km/a)	Possible amount of seaweed (t/a) (Sand beach)
Båstad	38,152	5,522	-	No data	901	4,975
Helsingborg	26,295	9,989	901	9,000	901	9,000
Höganäs	46,263	9,237	-	No data	901	8,323
Kristianstad - Täppet	1,000	1,000	2,629	2,629	2,629	2,629
Kävlinge	18,143	710	361	150	901	640
Landskrona	21,575	2,273	625	1,750	901	2,048
Lomma	11,584	5,124	357	563	901	4,617
Malmö	25,753	3,593	2,120	4,400	2,120	7,617
Simrishamn	48,741	19,011	-	-	218	4,144
Skurup	12,832	6,803	-	100	218	1,483
Trelleborg	33,091	19,824	218	1,035	218	4,322
Vellinge	44,963	0	109	1,275	218	0
Ystad - Saltsjöbadet	1,300	1,300	769	1,000	769	1,000
Ängelholm	14,491	5,658	-	No data	901	5,098
Bromölla	7,239	67	-	-	218	15
In total	**440,101**	**121,767**		**21,902**		**63,628**

The amount of seaweed that was collected in 2014 is 21,902 tons per year in total (see Table 6). However, the study shows that the possible amount of seaweed to be collected from sandy beaches is 63,628 tons per year in average. According to the study, only three of the fifteen municipalities are collecting the amount of seaweed that is currently possible, which are namely Helsingborg, Kristianstad - Täppet and Ystad - Saltsjöbadet. Other municipalities, such as Lomma, have a great potential to increase the amount of collected seaweed. The current amount of seaweed collected per year is 563 t. Nevertheless, with a coastline consisting of over 5 km of sandy beach, it is potentially possible to collect 4,617 t of seaweed per year.

Furthermore, Table 6 shows that the fifteen municipalities cover 440 km of coastline in total. Of these 440 km, 122 km are sandy beaches, which are not located in a nature reserve or protected area. This means that 122 km are available for seaweed collection by conventional collecting techniques.

The variations, shown in the Table 6, are large – from a possible amount of 218 t/km/a to 2,629 t/km/a – which shows that some factors have huge influence on how the seaweed is distributed on the coastline. These factors could be ocean currents, temperature, how steep the seabed is, wind and wave direction and strength, as well as where the seaweed grows. These are some of the factors that are used, when RUC have made estimations of the amount of seaweed that are available for collecting, which are shown in the section 4.6. Since the use of these factors includes a tinge of uncertainty, we recommend that the average amount of seaweed (860 t/km/a) for the whole coastline is used, when estimations are made for the southern parts of Sweden.

4.3. Denmark

In Denmark, many municipalities collect seaweed, but the information on amounts and technique, as well as what happens with the seaweed after collection, and is scarce. It is known that some municipalities move the seaweed from the beaches further out into the water so it can wash away with the currents, while others deposit it, either for good or until the tourist season has ended – where it is then delivered back into the water. Furthermore, some municipalities use it as a direct fertiliser, either mixed with garden waste at a recycle centre, and some have made an agreement with farmers.

Solrød municipality is the only municipality in Denmark where the collected seaweed is used as substrate for co-digestion in the local biogas plant.

Solrød has developed a collecting technique with a focus on minimal sand content as well as collecting the seaweed as fresh as possible due to the desire for a high methane content.

Therefore, the following section will be based on the experience from Solrød and how the currently used collection technique was developed and what was tried on the way to get here.

4.4. Solrød

Since 2008, the coast in Solrød has been cleaned from seaweed. The collection was arranged by the locals, who wished to have a tidy beach without bad odour. First, it was only a part of the long coastline, which was cleaned. In 2012, the locals from the municipality started to remove the seaweed from the entire coastline. In the beginning, the seaweed was used as a direct fertiliser with a temporary storage at the beach, but due to the smell and its nuisance to visitors of the beach, in 2010 a plan for a biogas plant arose.

In Solrød, a cooperation between local house owners, called “Strandrenselaug” is arranging the collection of seaweed. This is a collaboration between the locals and the municipality, and both are covering the expenses.

In the preliminary study, three collection techniques were investigated: a beach cleaner (1) (see Figure 11 and Figure 12), a tractor with an attached rake (2) (Figure 13, Figure 14 and Figure 15 and a harvester (3) (Figure 16). All techniques were disqualified due to the high content of sand collected with the marine biomass (20% sand for the rake, 60-90% for the beach cleaner, and 40-66% for the harvester). All measurements of sand content are based on dry matter (DM)) [5].

Figure 11: Beach cleaner and dumper

Figure 12: Beach cleaner machine tested in Solrød

Figure 13: Raking the seaweed

Figure 14: Rake attached to tractor

Figure 15: Raking the beach

Figure 16: Harvester tested for beach cleaning in Solrød

Fig. 11- Fig. 16: images by RUC

Trelleborg Municipality, in Sweden, tested collection techniques for seaweed as well, and therefore, the two municipalities teamed up. These techniques are further explained in the report, “A report on operating biogas facilities utilising anaerobic digestion of cast seaweed” [19]. This report explains the advantages and disadvantages of the different techniques that were tested in Solrød and Trelleborg. The testing of the collection techniques in Trelleborg was part of the Wetlands Algae Biogas (WAB-project), funded by the South Baltic INTERREG Programme. Seven techniques were tested in Trelleborg, which are summarised in Table 7.

Table 7: Classification of 7 different techniques for collecting area 1, from shore to 1 m depth, depending of coastal type (sandy beach, stony beach, port, or no beach). Category 1 represents technologies that are available and can be used without major changes.

Category	Collection technique	Coastal type(s) where collection can occur	Percentage of total coastline that would be suitable
1	GraWABting bucket	Sandy beach (beach and water)	70%
1	Pontoon machines	Harbour	5%
1	Large and small beach cleaners	Sandy beach (beach)	35%
2	Dry suction with collection barge	Sandy beach (beach) Stony beach (beach)	45%
2	Water pressure pump with collection barge	Sandy beach (water) Stony beach (water)	45%
3	Suction dredging		
3	Skimmer machines		

The different techniques were evaluated based on their suitability for the collection area, on how much modification is necessary before it will work for collection of seaweed, on how much material can be collected per hour and at what depth, and finally, on how much it costs to use the technique based on fuel consumption. The report from the WAB-project, and the investigations in Solrød concluded that when removing seaweed from shallow waters (up to 1 meter) and from the near shore sandy beach, a tractor with a grating bucket would be preferred.

In 2019, 1,521 tons of seaweed were collected from the beach in Solrød. This was done by a wheel loader with an attached grate shovel, which collects the seaweed from the lower part of the beach and the shallow water and piles it on the beach (see Figure 17). From here, the water can drain off and the seaweed is loaded onto a small dumper and transported to the nearby biogas plant.

The Strandrenselaug keeps an eye out for cast seaweed and when the beach needs to be cleaned it contacts a local entrepreneur, who holds the staff and machinery for the beach cleaning. This arrangement means that the seaweed is removed as quickly as possible (although only when the amount of seaweed is enough to be feasible) and the cleaning can begin before the locals will feel that the seaweed is a nuisance.

The applied technique means that the seaweed is collected as fresh as possible (both from the water and from the beach) and that the sand content is minimised. This is an advantage in terms of its utilisation in the biogas plant as well as for the biogas potential, since the seaweed does not start to degrade on the beach. Furthermore, the odour and other nuisances are minimised due to the quick collecting.

Figure 17: Pile of seaweed collected by wheel loader, picture from Solrød Strandrenselaug

In Solrød and the rest of Køge Bay, the so-called fedtemøg (Brown algae, mostly *Pilayella littoralis* and *Ectocarpus Siliculosus*) is a big nuisance and the beach and the water can be littered with it sometimes to a large extent (see Figure 18: and Figure 19:).

Figure 18: Brown algae at Solrød beach, picture from Solrød Strandrenselaug

Figure 19: Brown algae in the shallow water at Solrød Beach, picture from Solrød Strandrenselaug

These algae mean that the visitors at the beach need to go out to a great depth before the water is clean enough to bath in and sometimes all the water around the pier is filled with algae. When the algae are removed, the beach is left cleaned and the nuisances are gone (see Figure 20: and Figure 21:).

Figure 20: Cleaned beach in Solrød, picture from Solrød Strandrenselaug

Figure 21: Clean and tidy beach and water around the bathing jetty, picture from Solrød Strandrenselaug

4.5. Odden and Dragør

An example of another municipality with large quantities of seaweed is Dragør Municipality. In 2016 and 2017, between 257-286 tons of seaweed were collected from the beach called Mormor-stranden. In 2018, this amount was 611 tons. The seaweed collected in Dragør is disposed on a landfill, which in 2018 caused an expense of 299,973 DKK (around 40,227 EURO) [20]. Mormor-stranden is a small beach on the island of Amager, near Copenhagen (see Figure 22: The beach "Mormorstranden" in Dragør, Google Maps.). This beach is around 160 meters wide, which can be converted to 3,819 tons of seaweed per km in Dragør.

Figure 22: The beach "Mormorstranden" in Dragør, Google Maps.

In Odsherred municipality, the beaches are also cleaned from seaweed, which is then used as fertiliser.

In 2018, Odsherred collected 2,495 tons of seaweed at the 12 beaches that are suitable for cleaning. Each of these beaches is located near the access roads and only 100 m of each beach are cleaned (50 m to each side from the access road to the beach [21]). This corresponds to 2,079 tons of seaweed per kilometre in Odsherred.

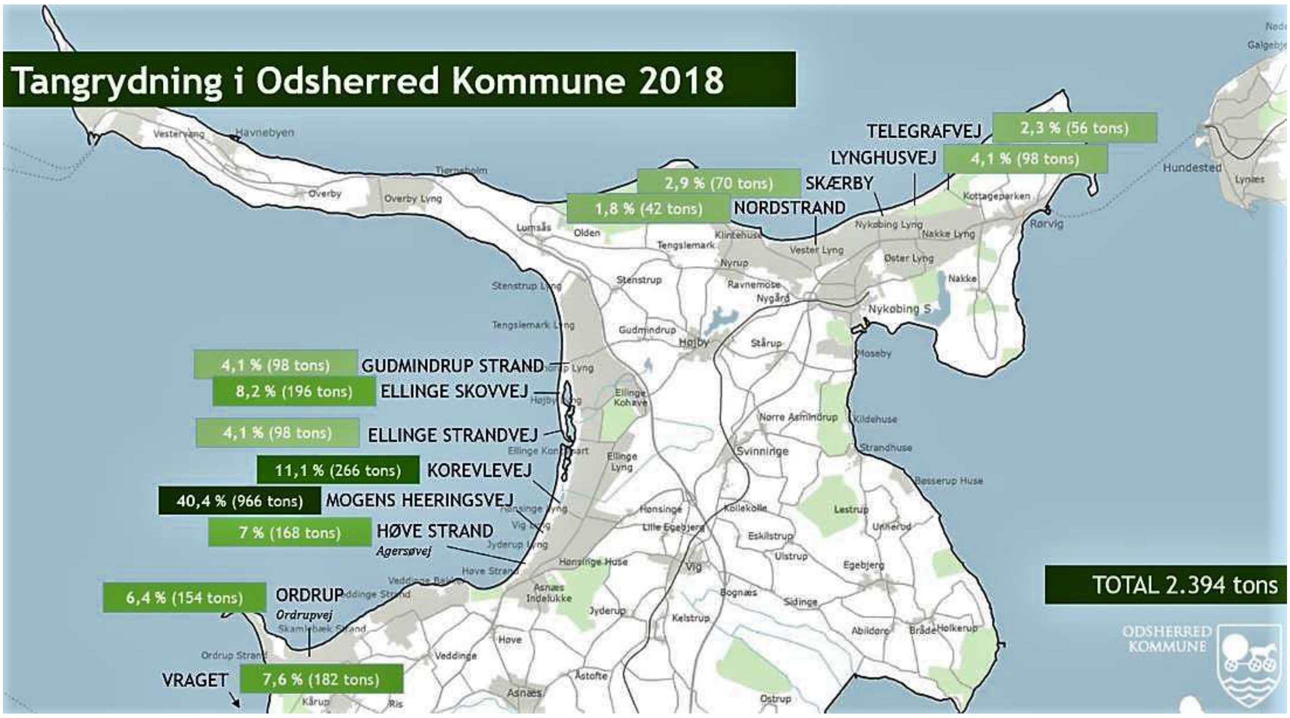


Figure 23: Seaweed amounts in Odsherred 2018 [21]

4.6. Estimations for South Baltic calculated by RUC

Based on collected amounts in the SB region, data for wind, temperature, ocean currents and geological information on sediment types (Figure 24), RUC has calculated some possible seaweed amounts for the region. These amounts are estimations for seaweed that are flushed into a sandy environment, meaning that these amounts do not cover areas with rough bottom such as bedrock: see the collection areas in Figure 24.

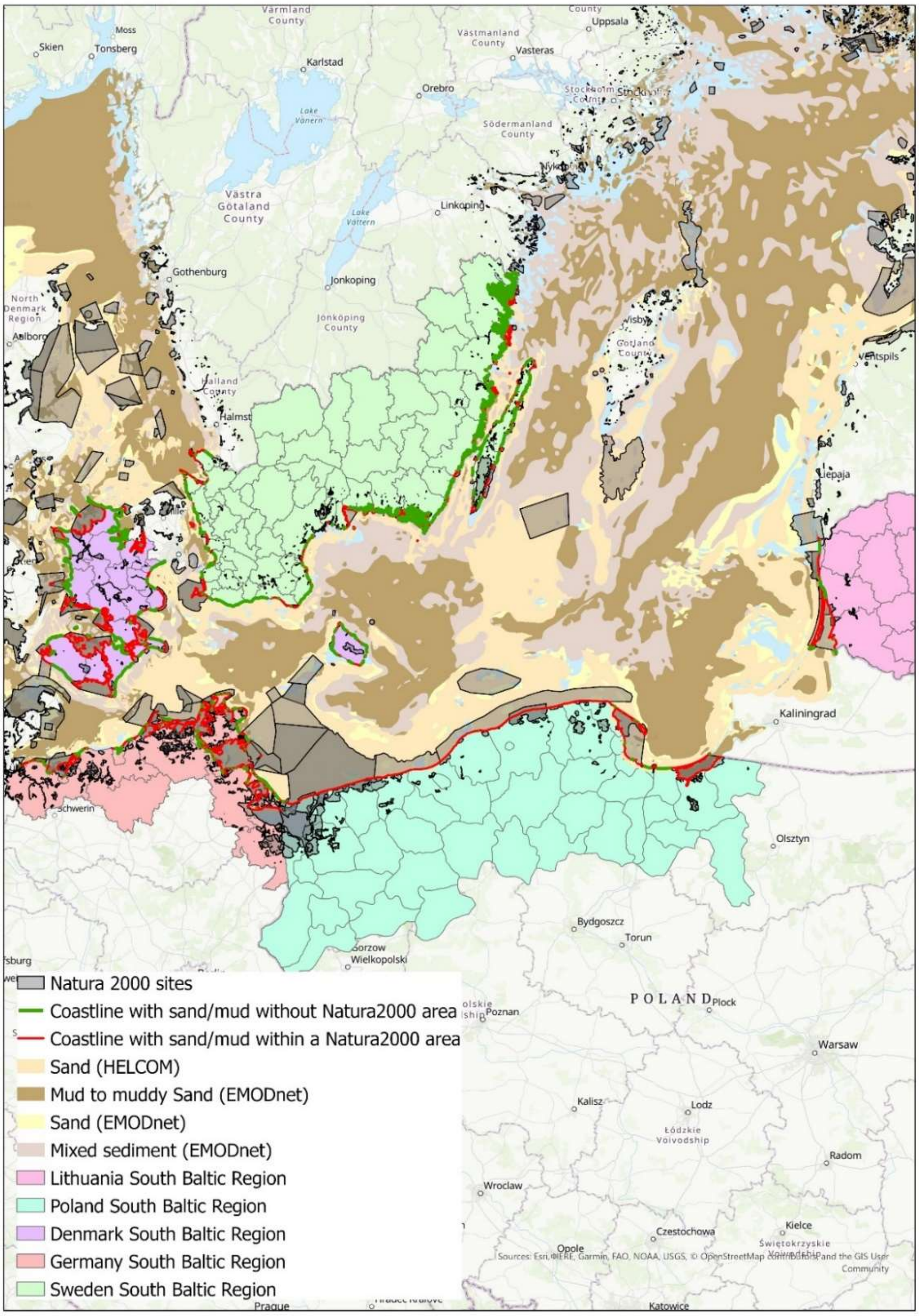


Figure 24: Sediment types in the South Baltic area, Natura 2000 sites and suitable coastline for seaweed collecting.

The calculated seaweed amounts are the seaweed that are influenced by sand, meaning that the actual amounts can either be lower or higher, depending on where it is collected, e.g. how far from the coast and on which type of coast.

Figure 24 shows the coastline, marked with the pink colour, which are the “suitable” coastlines, meaning that the coastline is either a sandy beach or something similar. The green part of the coastline is also sandy but is Natura 2000 areas. Depending on the reason for the protection of the area is should be considered if the collecting of seaweed will have an influence on the area's fragile nature and diversity.

To get more accurate estimations on the amounts of seaweed in a specific area it will be necessary to gain an overview over the production of seaweed – where it grows, how much and which types.

Table 8: Estimate of the total amount of seaweed, nitrogen and phosphorus in the five partner countries:

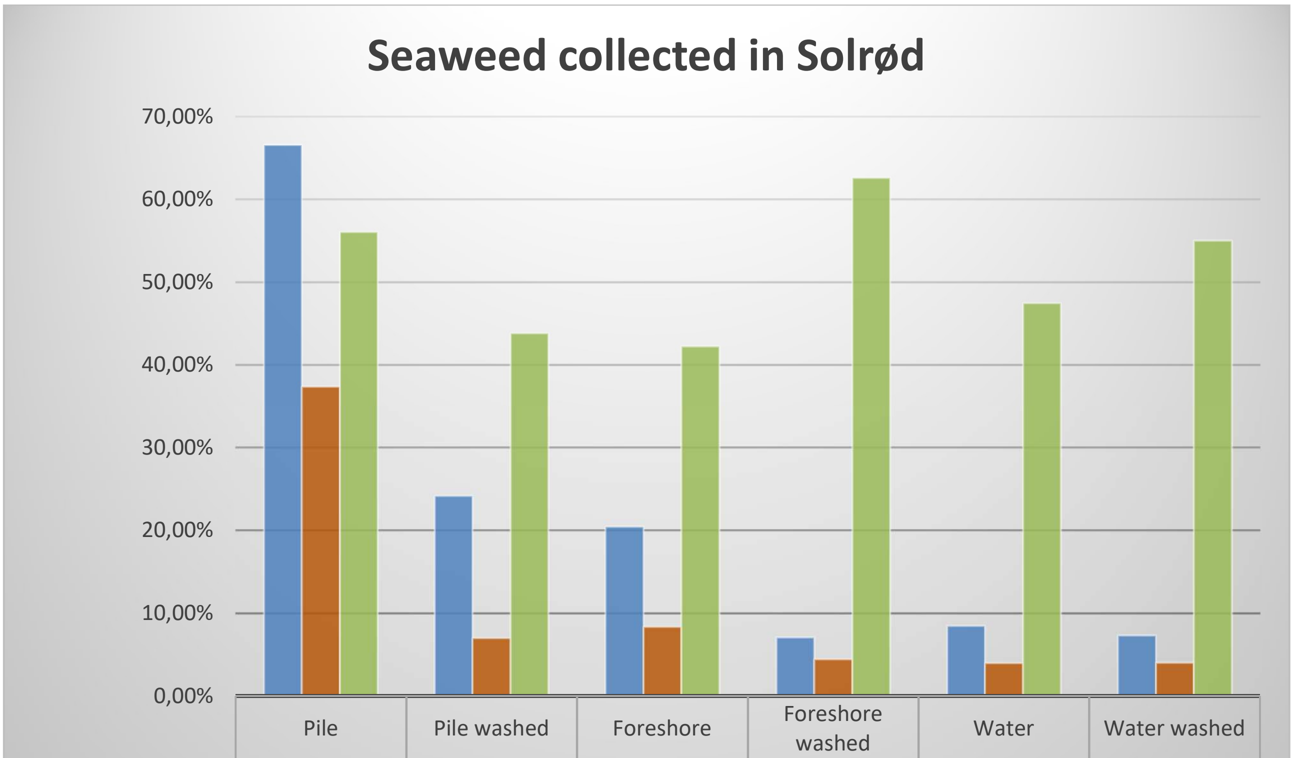
Region (including Natura 2000)	Coastline within Interreg South Baltic (km)	Suitable coastline (km)	Seaweed amount (t)	Seaweed (t/km)	DM (%)	Weight (t DM - dry matter)	Nitrogen N (t)	Phosp-horus P (t)
Sweden	4,643.08	3,907.26	1,143,951.87	292.78	15.00	171,592.78	1,034.70	156.15
Denmark	1,962.43	1,865.54	607,646.98	325.72	15.00	91,147.05	549.62	82.94
Lithuania	259.17	256.05	76,002.66	296.83	15.00	11,400.40	68.74	10.37
Germany	1,643.72	934.19	140,278.90	150.16	15.00	21,041.84	126.88	19.15
Poland	934.10	622.05	184,790.37	297.06	15.00	27,718.55	167.14	25.22
SUM	9,442.50	7,585.09	2,152,670.78	1,362.55	15.00	322,900.62	1,947.08	293.83

According to the estimations made by RUC, there are some uncertainties about the seaweed quantities in Denmark. In both, Odsherred and Dragør, the quantities are larger than the estimations, but the quantities from the two municipalities are based on short distances - around 200 m for each beach that is being cleaned. However, it is expected that the estimations are either correct or too low for the Danish seaweed quantities and that there is a great opportunity for collecting seaweed with the purpose of using the material for biogas production.

5. Sand separation techniques

The seaweed can contain up to 76.8% sand, if it is collected at the beach. If it is collected in the water, the sand content will be around 21.9% [5].

To remove the sand from the seaweed, the sand first needs to be loosened from the seaweeds surface. This can either be done by washing the seaweed in tap water at 52°C or above. Analysis performed by RUC, shows that when the seaweed is washed in 52°C, the dry matter content will decrease (Figure 25). 52°C is chosen due to the temperature of the process at Solrød Biogas plant. Other test shows that the sand can also be removed from the seaweed by washing it in nitric acid (HNO_3) with a pH at 0.28.



	Pile	Pile washed	Foreshore	Foreshore washed	Water	Water washed
Avarage DM	66,58%	24,16%	20,44%	7,11%	8,50%	7,34%
Avarage VS	37,38%	7,00%	8,37%	4,45%	4,00%	4,03%
Avarage DM/TS	56,07%	43,83%	42,24%	62,60%	47,46%	55,01%

Figure 25: Different methods of sand removal. Seaweed from beaches in Solrød Municipality.

When the sand can be loosened from the surface of the seaweed with existing technologies, it is possible to remove a large part of it from the seaweed.

Depending on the grain size of the sand, it is possible to remove up to 99% of the sand from the seaweed [22]. The finer the sand is the harder it is to remove from the seaweed. An analysis of sand from Denmark shows that 99.7% of the sand attached to the seaweed in Solrød is larger than 125 µm, and 99.4% in Odsherred. Because of the grain size of the sand found in Solrød and

Odsherred is mostly larger than 125 µm, it will be easier for a sand separator to separate the sand from the seaweed, which will be explained in the section below (see section 8.1. Sand separator).

Table 9: The grain size of the sand in Solrød and Odsherred measured in percentage.

Sieve size	Sand Solrød	Sand Odsherred
0,6 mm	29.01%	4.83%
250 µm	43.11%	23.58%
200 µm	19.29%	37.11%
125 µm	8.26%	33.86%
63 µm	0.34%	0.56%
<63 µm	0.00%	0.06%
Sum >125 µm	**91.40%**	**65.52%**

The seaweed species collected from the beach in Solrød were *Pilayella littoralis* and *Ectocarpus Siliculosus*, while in Odden, it was eelgrass *(Zostera marina)* and a small amount of bladder wrack *(Fucus vesiculosus)*. The seaweed from Odden was easier cleaned from the sand than the seaweed from Solrød, where the sand was stickier and harder to remove.

This means that, depending on which type of seaweed, different types of sand separation methods need to be considered. In some locations where bladder wrack and/or eelgrass are more common, it is probably sufficient to wash it a couple of times, before it enters e.g. a sand separator. For algae with more sticky surfaces, it will be necessary to use either hot water or chemicals to loosen the sand from the seaweeds surface.

5.1. Sand separator

The sand separator is an existing technology normally used for sand separation from cattle manure. The “sand washer” that the Danish company Stjernholm A/S can offer for separating sand from these seaweed, can extract 99% of the sand, when the particles are larger than 125 µm [22].

Figure 26: Sand washer from Stjernholm A/S [22]

The sand washer can be integrated in the existing process line, so that the seaweed is fed directly into the biogas plant.

The sand washer can secure a purity of the washed sand corresponding to a minimum ≥ 90% dry matter and ≤ 3% VS, around 95-99% of the sand can be reused and can for example be returned to the beach.

The processing plant for the separation of sand is built as one plant with a receiving tank for collection and mixing seaweed and sand, wastewater tank, and tank for sand-free seaweed, where the sand washing plant can be mounted on top, or close by.

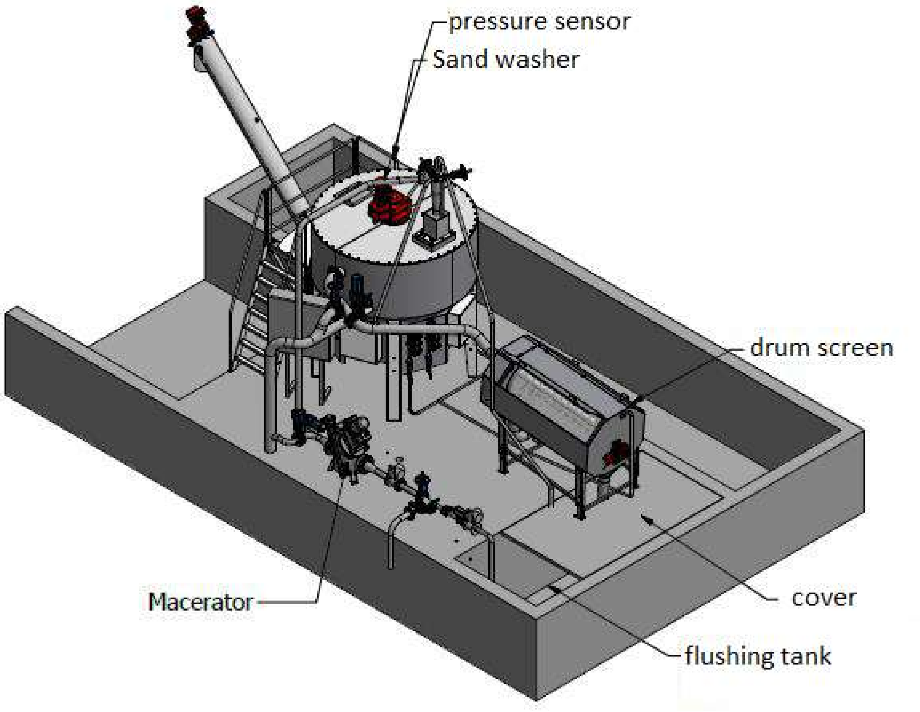


Figure 27: 3D model of a plant for separating sand from seaweed [22]

Figure 28: Seperated sand from Stjernholm A/S [22]

6. Recommendations

When collecting seaweed it should happen as soon as possible after it is washed up at the beach. The seaweed should be fresh, as it has a higher methane potential and the nutrients have not yet been released, as would otherwise occur if a degradation occurs. A degradation of seaweed will, beside from loss of methane and nutrients, be a nuisance due to the smell of rotten seaweed. The more fresh the seaweed is, the less sand it will contain. If possible, the seaweed should be collected while still in the water.

If the seaweed is collected on a sandy beach, the seaweed should go through some sort of pre-treatment before entering the biogas plant. This pre-treatment can consist of a form of washing as well as chopping the seaweed. The washing should happen with water that is at least 50°C, or with acid – though the acid can include risk to the biogas potential of the other substrates at the biogas plant.

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