COASTAL BIOGAS

Cluster On Anaerobic digestion environmental Services and nuTrients removAL

Report on potential of cast seaweed and policy frameworks in South Baltic Sea area

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Partners

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Preface

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Cover photo

Cast seaweed on Køge Bay beach (Denmark) photo by V. Akstinas

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Summary

Eutrophication has ecological, social and economic consequences and is one of the major environmental problems in the Baltic Sea. The use of cast seaweed in anaerobic digestion offers many opportunities of relevance for the Baltic Sea Region since it transfers low quality resources/wastes into a renewable high quality fuel. Moreover, it may help to mitigate eutrophication, reduce nutrient discharges into the Baltic Sea and take the first step towards a circular bio-economy. One of the tasks of the COASTAL Biogas project was to quantitatively identify the potential of cast seaweed and provide approaches for assessing the associated potential ecosystem service benefits in regards to resources and environment in the South Baltic Sea region. The conditions and possibilities to collect cast seaweed from the coasts of the South Baltic Sea region will be discussed in this report. A description of the coastal region of the Baltic Sea, its physico-geographical conditions, prevailing macroalgae species will be presented as well as a review on available information on cast seaweed composition on the shores of the project area, eutrophication problems and challenges related to cast seaweed management. Additionally, based on collected information and data provided by each project partner, the quantitative potential of cast seaweed for biogas production was estimated for the coastline of the project area in the territory of the Interreg South Baltic Programme. The estimation is approximate and has its shortcomings due to the different scale data, low accuracy of available data, or data absence. Since the methods of cast seaweed collection and its utilisation in biogas plants have to comply with policy frameworks in the EU as well as in each project partner country, a review on existing legislation documents regarding protected areas, waters, use of maritime substrates as potential RES (Renewable Energy Sources) feedstock, subsidies for 'green energy' production, and regulations on biogas power plant implementation was included. The review revealed that, to date, in the project partner countries, there are no clear procedure descriptions of the steps in the path of cast seaweed from the beach to biogas plant defined by the national law.

Introduction

The main objective of the project COASTAL Biogas is to promote the uptake of current technology related to anaerobic digestion of cast seaweed in combination with digestate utilisation. This should help to mitigate eutrophication, reduce nutrient discharges into the Baltic Sea and take a first step towards a circular bio-economy.

One of the tasks of the project is to quantitatively identify the potential of cast seaweed and provide methods and approaches for assessing the associated potential ecosystem service benefits regarding the resources and environment in the South Baltic Sea region. Each project partner (PP) from the South Baltic Sea area RUC (Denmark), FNR and UROS (Germany), GUT (Poland), BEIC (Sweden), and LEI (Lithuania) has contributed to identify the quantitative potential of cast seaweed on relevant coastlines in the region.

The report, first, gives a description of the coastal region of the Baltic Sea, its physico-geographical conditions and prevailing macroalgae species. Furthermore, it reviews available information on cast seaweed composition on the shores of the project area, eutrophication problems and challenges related to cast seaweed management. Then, approximate quantitative potential of cast seaweed for biogas production in PP countries is identified. Finally, EU directives, other international and national legislation documents related to cast seaweed issues in the project area are listed and shortly described. The methods of cast seaweed collection and its application in biogas plants have to comply with existing policy frameworks in the EU as well as in each project partner country regarding protected areas, waters, use of maritime substrates as potential RES (Renewable Energy Sources) feedstock, subsidies for 'green energy' production, and regulations on biogas power plant implementation. Therefore, whether cast seaweed can be removed and treated as municipal solid waste or whether it should be left on the beach as a vital part of the coastal ecosystem depends on many circumstances. It is a great challenge to balance between the wish for beaches free from cast seaweed, coastal ecosystem demands as well as related economic issues.

Experience related to cast seaweed management in all five project countries is reviewed based on the information gathered from all project partners. Some data were also acquired from local authorities (municipalities) using questionnaires specially created for this purpose.

1. Characterisation of the South Baltic Sea region

1.1. Physical-geographical conditions of the Baltic Sea

The Baltic Sea is a semi-enclosed inland sea, considered to be an extension of the North Atlantic Ocean, separating the Scandinavian Peninsula from the rest of continental Europe. It is connected to the Atlantic Ocean via the Kattegat Strait, Skagerrak Strait, and the North Sea. It is one of the largest brackish water bodies in the world, receiving both river and ocean water. According to different literature sources [1-4], the total surface area of the Baltic Sea is considered to be between 375,000 and 420,000 km^2 (without islands), it contains about 21,000 km^3 of water and its catchment area is close to 1.6 million km^2. The periphery amounts to about 8,000 km of coastline. The catchment area drained by the rivers bringing fresh water into the Baltic Sea is about four times as large as the sea itself (Figure 1). The Baltic Sea is a relatively shallow sea; its average depth is around 55 m. The deepest waters are located in the Landsort Deep in the Baltic Proper, where depths of 459 m have been recorded.

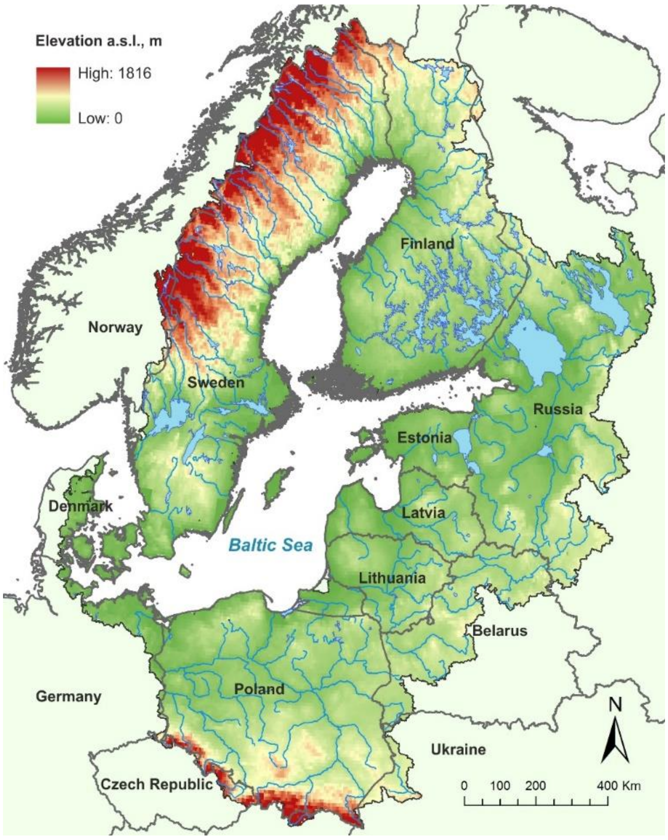


Figure 1: The catchment area of the Baltic Sea (by V. Akstinas)

The Baltic Sea is a relatively isolated water body; the only outlet to the ocean is located between Denmark and Norway. Hence, the exchange of the Baltic Sea water with water from the Atlantic Ocean occurs very slowly. It takes about 25-35 years for all the Baltic Sea water to be completely exchanged [5].

The main coastal types in the Baltic are hard rock coasts (mainly in the north), soft rock coasts alternated with shingle and sandy beaches (mainly in the southwest area) and soft rock coasts alternated with sandy beaches and dunes (mainly in the southern area).

The Baltic Sea is positioned in Northern Europe and bordered by Finland, Sweden, Denmark, Germany, Poland, Russia, Lithuania, Latvia and Estonia as well as its numerous islands. Institutions from five of these countries - i.e. Denmark, Germany, Lithuania, Poland, and Sweden - belong to the South Baltic Sea area (Figure 1) and take part in the COASTAL Biogas project.

Denmark

Denmark is situated in Northern Europe and consists of the mainland called Jutland or Cimbrian Peninsula and the Danish Archipelago islands in the Baltic Sea. The Danish coastline borders the Baltic Sea in the east and the North Sea in the west. Denmark´s coastline exceeds 6,939 km, whereas the largest part (5,052 km) faces the Baltic Sea. This is by far the longest coastline of all the Baltic Sea countries. The Danish Baltic coast is, in most places, characterised by the flatness of the landscape, by dunes and shallow wetland areas and by softly curved bays.

Germany

The German coast extends over 3,600 km on both the North and the Baltic Seas. The length of the German Baltic Sea coast is 1,945 km. This coastline is characterised by steep coast and beaches with fine, white sand, bays and fjords. More than 50% of the coastline belongs to the so-called

Bodden Coast (shallow bays and inlets cut off from the open Baltic Sea by islands, peninsulas, and narrow spits) part of which consists of protected areas.

Lithuania
The Lithuanian zone of the Baltic Sea is situated in the south-eastern part of the Baltic Proper. The total length of Lithuanian Baltic Sea coastline is almost 90 km. It includes the mainland coast (38.49 km) and the Curonian Spit coast (51.03 km). The distance between the shores of Klaipėda Strait is 1.14 km. The Curonian Spit (0.4 – 4.0 km wide) almost cuts off the Curonian Lagoon from the Baltic Sea, while the Klaipėda Strait connects them. The coastline of the Lithuanian Baltic consists mainly of sandy and rare pebble beach stretches. The average width of beaches in the continental zone is around 92 m, while in the Curonian Spit it is 136 m.

Poland
Poland is located in Central Europe; its northern part, which is bordered by the Baltic Sea, belongs to South Baltic Shore lands and is divided into three macro regions: Szczecin Shore land, Koszalin Shore land and Gdansk Shore land. The South Baltic Shore lands stretch from the Bay of Kiel (Germany) in the west to the Vistula Lagoon (Poland) in the east. The Polish coastline is considered to be 770 km long. The Polish marine zone comprises the eastern and western part of the southern Baltic Proper and constitutes about 10% of the entire Baltic. The coastline is rather smooth and regular. Major part of the Polish coast is characterised by sandy beaches. The width of the beaches does not exceed 100 m, while the total area is around 20 km^2.

Sweden
Sweden is located in Northern Europe, in the eastern part of the Scandinavian Peninsula. The eastern and southern coasts of Sweden lie at the Baltic Sea (approx. 2,150 km). There are vast archipelagos (over 220,000 islands) in the south-east of Sweden. Marine and coastal biotope complexes along the Swedish South Baltic coast mainly consist of rocky coasts and cliffs, sandy and moraine coasts, bays and lagoons. The sandy coasts are especially characteristic to Skåne (east coast and the south-eastern part), to the coasts of large islands in the Baltic Sea (Öland and Gotland) and to archipelagos along several parts of the coast.

1.2. Seaweed in the Baltic Sea

The most diverse biological communities in the Baltic Sea are found along the coast. However, they are much less diverse than those found on the intertidal shores of the oceans. The isolation of a shallow water body from the surrounding sea influences the habitat type. The bottom substrate of the Baltic Sea, which varies from bedrock to soft mud, forms the basis for unique communities of animals, plants and algae. Community composition is also influenced by differences in salinity, varying water temperatures, depth, changing exposure to wave action and other physicochemical characteristics. It is often hard to determine where one community ends and another one takes over - the changing community composition is more of a continuum [6]. The Baltic Sea is often described as a species-poor ecosystem [7, 8, 9]. The number of marine species gradually drops from the west coast of Sweden (Kattegat) through the Baltic Proper towards the Gulf of Bothnia and the Gulf of Finland [10]. Different types of shores host characteristic groups of flora and fauna. The various plant and animal species are, however, not restricted to just one type of habitat and are commonly found on different kinds of shores. Coastal ecosystems are much more unstable than pelagic or deep benthic ecosystems, due to factors such as a large temperature range, wave exposure and the abrasive action of ice. Coastal communities are characterised by seasonal cycles [11].

Most typical plants of the marine benthic habitats are various seaweeds. Stands of seaweed provide food and shelter for a great variety of marine organisms as well as spawning sites for fish. Seaweed beds also support large populations of migrating water birds such as herbivorous swans, diving ducks, geese and predatory wading birds [12]. Hundreds of different types of vegetation can be found in the ecosystem of the Baltic Sea. A checklist of the Baltic Sea macrophyte species [13] includes 531 taxa of macroalgae, aquatic vascular plants, charophytes and bryophytes. These data make it possible to establish the distribution of each species across the Baltic Sea. Figure 2 shows species diversity per sub-basin.

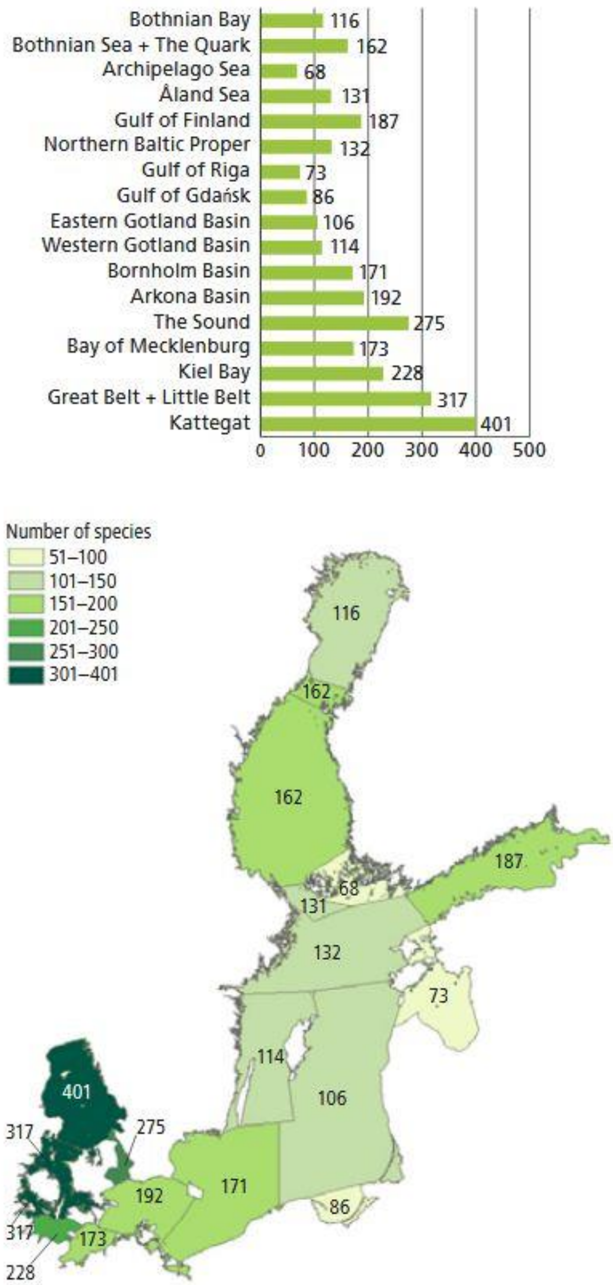
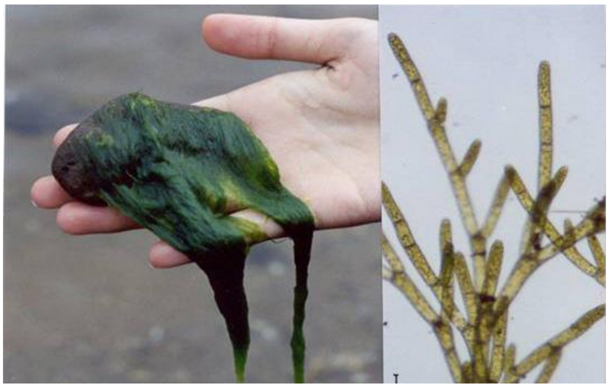


Figure 2: Number of macrophyte species per Baltic Sea sub-basin [13]

The Baltic coastal zone is an area of high primary production, which is partly due to the riverine input of nutrients from the catchment areas and partly due to the shallowness of the coastal area. Large parts of the coastal zone belong to the phytal zone, i.e. the part of a water body that is sufficiently shallow for enough light to reach the bottom to enable the growth of rooted green plants and attached macroalgae. Macrophytes play a major role in the phytal areas of the coastal zone. The species composition of an area is dependent on its bottom substrate. The bottom may either be hard, consisting of bedrock or other rocky substrates, or soft, consisting of sand, clay or organic-based mud [11]. In this report, the focus will rest on marine macrophytes, such as seaweeds. The word seaweed is often used to describe perennial macroalgae, but also refers to seagrasses. Marine macroalgae, or seaweeds, are plant-like organisms that generally live attached to rocks or other hard substrates in coastal areas. Structure of seaweeds or seagrasses shows big variation, ranging from simple flattened laminae to complex formations of branches or roots.
Macroalgae fall into three distinct groups: brown algae (*Phaeophyta*), green algae (*Chlorophyta*) and red algae (*Rhodophyta*) that differ in colour depending on dominant pigment or pigment composition (Figure 3). Eelgrass (*Zostera marina*) is an important macrophyte species on shallow sandy bottoms in the southern and central Baltic Sea. The benthic vegetation on hard substrates is dominated by brown and red seaweeds [4]. According to the Checklist of the Baltic Sea Macro-species [13], 129 species of brown algae, 109 species of green algae and 173 species of red algae are known to occur in the Baltic Sea.


(a)


(b)


(c)


(d)

Figure 3: Seaweed species: a) *Fucus vesiculosus* (brown algae) [14]; b) *Cladophora glomerata* (green algae) [15]; c) *Furcellaria lumbricalis* (red algae) [16]; d) *Zostera marina* (eelgrass) [14]

The main species of the macro algal community characterised by filamentous algae are the green algae *Cladophora glomerata* and the brown algae *Pylaiella littoralis*. These algae are opportunistic, annual species and their growth form and abundance vary seasonally. The filamentous algae are important as food sources and habitat for many invertebrates and their juvenile stages [11]. During winter, the abrasive action of the ice tears the annual filamentous algae off the rock surface. In spring a new generation of filamentous algae colonises these bare surfaces. During summer, *Cladophora glomerata* forms drifting mats [17].

In the project area countries, the most common species (especially prevailing in Sweden) is brown algae *Fucus vesiculosus*, known as bladder wrack. It is the most important perennial algae in the Baltic Sea. It serves many groups of fauna as food supply, spawning area or hiding place from predators. However, recently, a decline of this species in many areas of the Baltic Sea has been observed due to water pollution and decreased water transparency. The amount of other common brown algae, *Pylaiella littoralis*, on the opposite, is observed to increase in coastal areas around the world, including the Baltic Sea. *Furcellaria lumbricalis* is a widespread red algae species in the Baltic Sea. Many fish species, among them the Baltic herring, use this algae as spawning grounds. Another red algae, widely spread in the Baltic Sea, is *Ceramium Tenuicorne* [18]. Among green algae, species of the genus *Cladophora* are typical and become more abundant in the project area. Over the past few decades, developments of green filamentous algae, such as *Cladophora* and *Enteromorpha* have increased in the Baltic coastal areas [19]. *Zostera marina* (Common Eelgrass), which is also identified as seaweed but belongs to seagrass species is also ecologically very important (it is used as a shelter by many animal species) and widespread in the Baltic ecosystem, as well as in the coastal waters of the project countries (especially abundant in the German coast).

The lists of threatened and declining species of algae and vascular plants of the South Baltic Sea area contain 10 and 2 species, respectively [20].

2. Cast seaweed and its management in the South Baltic Sea coastal region

2.1. Eutrophication and cast seaweed

A major problem of the Baltic Sea is eutrophication. Over the last century, this sea has become a highly eutrophic water body. Eutrophication in the Baltic Sea is to a large extent driven by anthropogenic inputs of nutrients (mainly nitrogen and phosphorus), resulting in nutrient over-enrichment and/or changes in nutrient ratios causing elevated levels of macro vegetation, increased turbidity, oxygen depletion in bottom waters, changes in species composition and increase of adverse blooms of algae. At least 97% of the sea area was assessed as eutrophied in 2011–2016 according to the second holistic assessment by the Helsinki Commission (HELCOM) [4]. This indicates that despite the measures taken to reduce external inputs of nutrients to the sea, good water quality status has not yet been reached. Nutrient load reduction to the Baltic Sea becomes even more important in warmer climate conditions, as higher water temperature accelerates the eutrophication process.

Eutrophication also can be due to the naturally occurring process called internal loading. In the Baltic Sea the internal loading is significantly enhanced by the anthropogenic processes, as the cycles of nitrogen, phosphorus and oxygen are interconnected. These interconnected processes are referred to as the vicious cycle of the Baltic Sea [11]. Natural background sources, such as erosion or runoff from unused areas, contribute to the total waterborne nutrient load and are the third largest nutrient source.

Nutrients enter the Baltic Sea through waterborne (rivers and direct discharge from point sources) and airborne (atmospheric deposition directly into the sea) inputs. In the case of the Baltic Sea, the main eutrophying nutrients are nitrogen and phosphorus. About 75% of the nitrogen and 95-

99% of phosphorus enter the Baltic Sea as waterborne input [21]. The unique characteristics of the Baltic Sea, such as limited water exchange with the North Sea and a long residence time of the water, make this water body particularly vulnerable to extensive inputs of nutrients.

The main source of nitrogen inputs to the Baltic Sea coastal waters is agricultural effluents discharged through rivers. Intensive farming, manure production, soil cultivation and use of fertilisers are the main causes of nitrogen inputs. Another important source is atmospheric nitrogen deposition. This process is the result of fossil fuel combustion in industry, traffic and households as well as ammonia emissions from livestock husbandry. The major sources of phosphorus are treated and untreated discharges into the sea from industry as well as soil erosion. In 2010, the total waterborne input of nitrogen was 894,000 tonnes and that of phosphorus 36,200 tonnes. The largest loads of waterborne nitrogen originated from Poland (34%), Sweden (13%), Russia (12%) and Latvia (10%). For phosphorus, the main waterborne sources are as follows: Poland (41%), Russia (17%), Sweden (10%) and Latvia (9%). It should be noted, however, that the total waterborne nutrient loads for Latvia, Lithuania, Poland and Sweden also include transboundary loads [22].

Eutrophication has both positive and negative effects. Initially, the effects are often positive, with higher primary production (increasing abundance of zooplankton, benthic fauna and plankton-eating fish). However, as eutrophication progresses, the negative effects become more important and the ecosystem is disturbed. The increased primary production leads to higher rates of sedimentation, and more organic material is deposited at the bottom of the sea. The bacterial decomposition of these masses of organic material consumes oxygen and as a result, oxygen conditions deteriorate. When oxygen levels in the water are depleted, decomposing bacteria start to release hydrogen sulphide (H_2S), which is extremely toxic. Gradually, the living conditions for fish and the benthic fauna deteriorate. As conditions become anoxic, fish move away from the area, and mass mortality of benthic fauna results in large areas of the seafloor becoming devoid of life. The negative effects of eutrophication on marine ecosystems include: algal blooms, increased growth of macroalgae, increased turbidity and sedimentation, oxygen consumption, oxygen depletion in lower water layers, in some cases mortality of benthic fauna [23, 24]. Nitrogen input into the Baltic Sea fosters an excessive production of planktonic algae, whereas input of phosphorus stimulates the growth of cyanobacteria, which are toxic to humans and animals. As a result of the excessive growth of planktonic algae, algal blooms are formed, which are a frequent phenomenon in the Baltic Sea. Massive algal blooms harm recreational use of the sea and its resources. Algal blooms occur in most parts of the South Baltic Sea during summer time. With increasing eutrophication in coastal areas, mass developments of annual filamentous algae, such as *Pylaiella littoralis* and *Enteromorpha* spp., increase. Annual seaweeds detach from the sea bottom during the late summer and early autumn. Perennial species usually are detached from the bottom because of wave exposure. These wandering algae called “macro-algal blooms” eventually are washed up towards the shores. The overall goal of HELCOM is to have a Baltic Sea unaffected by eutrophication [25]. This report seeks to obtain information, which might help to address the problem of increased amounts of cast seaweed on the beaches of the Baltic Sea caused by eutrophication.

2.2. Species composition of cast seaweed on the shores of the South Baltic Sea countries

Seaweed can be found in three different states: attached to the substrate, free-floating or beach cast [26]. Storm waves tear off the seaweed from the rocky seafloor. Loose seaweeds either sink to the bottom of the sea, are being washed up on the shore or winds and sea currents move floating mats of seaweeds from one place to another. Surface-drifting macroalgae or seagrasses move with the prevailing winds, whereas bottom-drifting macroalgae are more influenced by currents [27].

The different species of seaweed, which are washed ashore during strong winds, deposit on the beaches or other coastal types. Certain amounts of seaweed can be found along the beaches in the water. Seaweed accumulated on the beaches usually forms the beach-cast wrack walls (Figure 4). Fresher algae are usually found in the sea rather than on the shore. Seaweed on the beaches can be dry or decomposed to such an extent that it is difficult to identify the dominant species [28]. Dense algal mats may cause anoxia or hypoxia and greatly reduce the recreational value of the area [29].

(a) (b)

Figure 4: Washed ashore seaweed: a) Palanga beach (Lithuania) photo by D. Šarauskienė; b) Køge Bay beach (Denmark) photo by V. Akstinas

Washed ashore seaweed species composition and quantities may depend on many factors, such as algal distribution and abundance, storm events and season (month). Since the loose algae can relocate due to strong winds and sea currents, completely uncharacteristic species of the coastal waters can be detected on the shore. Each seaweed species has an individual cycle of growth and abundance. Some are annuals, occurring only for a season or few seasons and some are perennials that can persist for several years [30].

Marine biomass may be considered as renewable energy resource, especially the one grown uncontrollably due to increased levels of nutrient discharges into the water body. Seaweed is rich in carbohydrates and, if it can be efficiently converted, may be suitable for the production of renewable fuels, such as biogas. Different species of marine vegetation washed ashore may have different gas yields. If the main driver is to produce biogas, it is important to identify the main species of interest in respect to their potential use for biogas production. Other drivers could be closing the nutrient cycle and hence eutrophication as well as producing organic fertiliser. The majority of algae biomass worldwide comes from a relatively small number of species in the orders *Laminariales* and *Fucales* [31]. The subtidal large brown kelps of the order *Laminariales* have been identified as having the greatest potential for bioconversion to energy [32]. Among green macroalgae, *Ulva* is the most important prospect from an energy perspective [33].

Denmark

According to the monitoring data of 1989-2003, a total of 81 algal taxa were found in the Danish Baltic Sea. The native algae prevail, while the alien component can be considered relatively small [34]. Seven species of algae were found to prevail among native species: filamentous brown algae *Ectocarpus siliculosus*, red algae *Ceramium virgatum*, *Phycodrys rubens*, *Polysiphonia fucoides*, and *Furcellaria lumbricalis*, brown algae *Fucus vesiculosus* and red algae *Coccotylus truncatus*. Alien macroalgae in Denmark's Baltic Sea are red algae *Dasya baillouviana* and brown algae *Fucus evanescens* in the Baltic west.

In scientific literature, on Danish coasts, brown macroalgae species *Macrocystis pyearifera* (common name: Giant kelp) is mentioned in the context of cast seaweed utilisation for biogas production [35]. Around Denmark, *Laminaria digitata* and *Saccharina latissima* are particularly common brown macroalgae species that receive much attention in respect to their use for biogas [36]. Cast seaweed, which is collected from the beaches and used as co-substrate in Solrød biogas plant also consists of *Ulva lactuca*, eelgrass *Zostera marina* and filamentous brown alga *Pylaiella littoralis* and *Ectocarpus siliculosus* [37, 38].

Germany

In the German part of the Baltic Sea, shallow stone and boulder grounds are rich in macrophytes. Common algae are *Cladophora* spp. and *Enteromorpha* spp. in the shallow zone, whereas *Fucus vesiculosus* may reach down to 10 m and red algae like *Phyllophora, Ceramium, Polysiphonia*, *Delesseria sanguinea and Furcellaria fastigiata* up to a depth of 20 m. Remarkable *Laminaria saccharina* occurrences have been found down to 22 m depth at Walkyrien Ground, on the slopes of the Kadet Trench and around northern Rügen [10]. A unique feature is the dense occurrence of brown algae *Chorda tomentosa* on stone fields of the Adler Ground [39, 40]. Sand and fine sand bottom, where depth is 0-10 m can be settled by eelgrass (*Zostera marina*). Eelgrass meadows are typical for the shallow waters. In some regions, drifting brown and red algae may cover the bottom as well [40].

In Germany, the species found in stranded material are mainly *Zostera* (ealgrass) and brown algae *Fucus* species *(Fucus vesiculosus* and *Fucus serratus*) [41]. In other studies macroalgae *Fucus vesiculosus* is mentioned in respect of its use in methane production by applying thermo-acidic pre-treatment to enhance hydrolysis of polymeric molecules in biomass [42].

Lithuania

About 40 species of macroalgae have been identified at the Lithuanian Baltic coastline and in the northern part of the Curonian Lagoon. Such a small amount of algae species is determined by the following environmental conditions: open sandy coasts with scarce boulder fields as the only hard substrate and salinity varying from 4 to 7 ‰ [43]. Macroalgae are most often found on boulders because the sand is too moveable to allow algae to settle there.

Algae of all types are found on the Lithuanian coast. *Furcellaria lumbricalis*, *Polysiphonia fucoides, Ceramium tenuicorne* and *Coccotylus truncatus* are the most commonly found red algae species. The most important and widespread species of algae in this area is a perennial red algae black carrageen (*Furcellaria lumbricalis*) [44]. Brown macroalgae bladder wrack (*Fucus vesiculosus*) hardly grows in Lithuanian coastal waters because of strong swells during storms, but after heavy storms these algae are thrown ashore by the waves. This algae species, as well as the red algae *Furcellaria lumbricalis,* almost disappeared in the area evidently due to recent changes in

environmental conditions (increased turbidity and severe storms). Simultaneously, brown algae *Pylaiella littorals* have increased in coastal areas around the world, including the Baltic Sea [19].
The most common green algae genus in the Lithuanian coast is *Cladophora*. It is commonly found in the shallows, on rocks. Upper littoral of the coastline is occupied by opportunistic filamentous algae communities dominated by *Cladophora glomerata* and *Enteromorpha intestinalis* [43].

Poland

The species composition of seaweed in the Gulf of Gdansk – especially its shallow part, i.e. the Puck Bay – has changed in recent decades [45]. Two species of filamentous brown algae *Ectocarpus siliculosus* and *Pylaiella littoralis* have become dominant in the Puck Bay, meanwhile an algae community with *Fucus vesiculosus* and *Furcellaria spp*. as dominant species may no longer be present. The range of seagrass *Zostera marina* has decreased significantly, too [46]. Green algae of this region represent *Enteromorpha* sp., *Cladophora* sp. as well as *Chara baltica* [45].
Both, good light conditions and the rocky bottom in the Slupsk Bank favour the development of macrophytes: *Fucus vesiculosus*, *Furcellaria lumbricalis*, *Delesseria sanguinea* and some others, which have probably disappeared in the Gulf of Gdansk [10].
In Poland, on the Sopot beach, identified dominant macroalgae species are *Cladophora* spp (green algae), *Enteromorpha* spp. (green), *Pylaiella littoralis* (brown) and *Ceramium* spp. (red). However, green algae of genus *Ulotrix* spp. and S*tigeoclonium* spp., brown algae *Ectocarpus* spp., red algae *Polysiphonia* spp. and *Phyllophora brodiaei* as well as seagrass *Zostera marina* can also be detected [47].

Sweden

Swedish studies indicate a dominance of red macroalgae in the Baltic Sea coast during the majority of the years [48, 49]. Most common red algae are *Polysiphonia fucoides, Furcellaria lumbricalis* and *Ceramium tenuicorne.* However, the green algae *Cladophora glomerata* and *Enteromorpha intestinalis* as well as the brown algae *Ectocarpus siliculosus* are also prevalent along the Swedish Baltic Sea coast [50].
Species composition in the beach cast depends on the season. Collections of algae from Trelleborg beaches show that filamentous red algae *Polysiphonia fucoides* dominate in February and June, while the red algae *Furcellaria lumbricalis* with small contribution of *Polysiphonia fucoides* dominate in March. Freshly grown, the brown algae *Ectocarpus siliculosus* with significant presence of the red algae *Ceramium tenuicorne* dominate from the end of April [51].
The wandering brown algae bladder wrack (*Fucus vesiculosus*), washed up towards the shores, can be used for biogas production [52]. In the studies that were carried out, red algae were most common along the coasts of Öland and Gotland, while fine-threaded green algae predominated among the collected algae along the mainland coast.
Seaweed species found in the project countries are listed in Table 1.

Table 1: Summary of seaweed species found in the project countries

Country	Red algae (*Rhodophyta*)	Brown algae (*Phacophyta*)	Green algae (*Chlorophyta*)	Seagrass
Denmark	*Ceramium virgatum* *Phycodrys rubens* *Polysiphonia fucoides* *Furcellaria lumbricalis* *Dasya baillouviana*	*Ectocarpus siliculosus* *Fucus vesiculosus* *Coccotylus truncatus* *Pylaiella littoralis* *Fucus evanescens* *Macrocystis pyearifera* *Laminaria digitate* *Saccharina latissimi*	*Ulva intestinalis* *Ulva lactuca* *Cladophora glomerata*	*Zostera marina*
Germany	*Phyllophora crispa* *Ceramium spp.* *Polysiphonia spp.* *Delesseria sanguinea* *Furcellaria fastigiata* *Furcellaria lumbricalis* *Laminaria saccharina*	*Fucus vesiculosus* *Fucus serratus* *Chorda tomentosa* *Pylaiella littoralis*	*Ulva intestinalis* *Cladophora sp.* *Enteromorpha sp.*	*Zostera marina*
Lithuania	*Furcellaria lumbricalis* *Coccotylus truncatus* *Polysiphonia fucoides* *Ceramium tenuicorne*	*Pylaiella littoralis* *Fucus vesiculosus* *Ectocarpius siliculosus*	*Ulva intestinalis* *Cladophora rupestris* *Cladophora glomerata* *Enteromorpha intestinalis* *Ulotrix subflaccida*	*Zostera marina*
Poland	*Furcellaria lumbricalis* *Delesseria sanguinea* *Ceramium spp.* *Polysiphonia spp* *Phyllophora brodiaei* *Coccotylus truncatus*	*Ectocarpus siliculosus* *Pylaiella littoralis* *Fucus vesiculosus*	*Enteromorpha sp.* *Cladophora sp.* *Chara baltica* *Ulotrix spp.* *Stigeoclonium spp*	*Zostera marina*
Sweden	*Furcellaria lumbricalis* *Polysiphonia fucoide* *Ceramium tenuicorne* *Coccotylus truncatus*	*Fucus vesiculosus* *Ectocarpus siliculosus* *Pylaiella littoralis* *Fucus serratus*	*Ulva intestinalis* *Cladophora glomerata* *Enteromorpha intestinalis*	*Zostera marina*

In the studied area, concerning the amounts and numbers of cases of use for biogas production, brown algae species are among the most often mentioned. According to different literature sources, species of red and brown macroalgae have the greatest methane potential (Table 2) [53] and these algae groups are the dominant among Baltic macrophytes [4, 13].

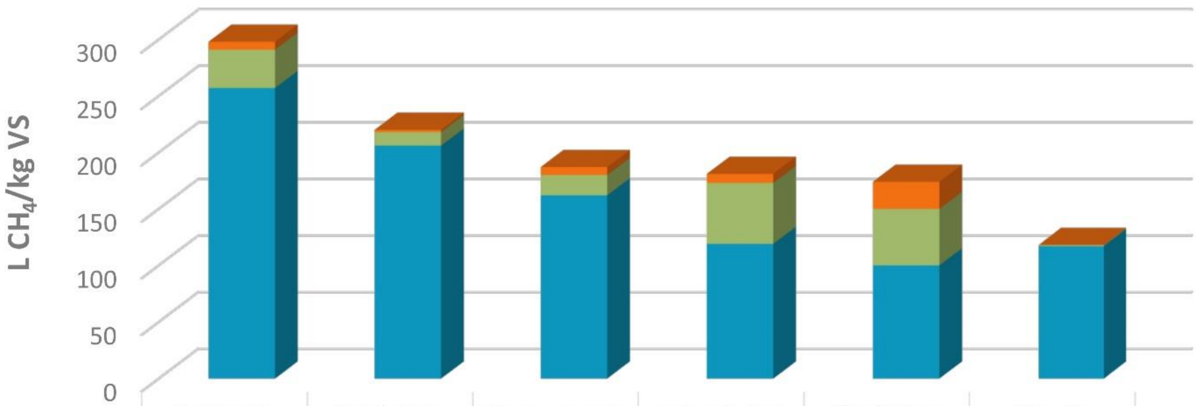
Table 2: Methane yield from macroalgae (modified from [53])

	Methane yield	
	L CH4/kg VS	Nm3 CH4/kg VS
Macroalgae from Trelleborg beach (April/May)[a]		0.2
Macroalgae from Trelleborg beach (February)[a]		0.125
Green algae		
Ulva 15%, l CH4/kg VS[b]	227	0.23
Ulva 30%, l CH4/kg VS[b]	204	0.20
Ulva 45%, l CH4/kg VS[b]	221	0.22
Ulva 60%, l CH4/kg VS[b]	166	0.17
Ulva 75%, l CH4/kg VS[b]	163	0.16
Ulva low N[b]	196	0.20
Ulva high N[b]	190	0.19
Control, l CH4/kg VS[b]	213	0.21
Ulva sp. (non-washed)[c]	110	0.11
Ulva sp. (washed)[c]	94	0.09
Ulva sp. (non-ground)[c]	145	0.15
Ulva sp. (ground)[c]	177	0.18
Brown algae[c]		
Fucus vesiculosus	442	0.44
Laminaria saccharina	410	0.41
Laminaria digitata	442	0.44
Red algae[c]		
Palmaria palmata	453	0.45
Porphyra umbilicalis	442	0.44
Average[d]		0.31 ± 0.14

[a] [54]; [b] [55]; [c] [56]; [d] estimated taking into account values given by [54] and [56] that relates to the methane yield from red algae

Brown algae *Laminaria digitata* was selected for an assessment of possibility to use it for biogas production by scientists in the UK as well [57]. In the joint UK and Irish project 'BioMara' five potential seaweed species, *Saccorhiza polyschides*, *Ulva spp*., *Laminaria digitata*, *Fucus serratus* and *Saccharina latissima*, were co-digested individually with bovine slurry. The combination of *Saccharina latissima* with slurry produced the maximum methane yield (335 mL g volatile solids^{-1}) followed by *Saccorhiza polyschides* (255 mL g volatile solids^{-1}) [32]. Gegg and Wells [58] summarise that in the UK brown algae have been identified as having the greatest potential for bioconversion to energy. Particular species that have been suggested for biofuel production include already mentioned *Laminaria saccharina* and *Saccharina latissimi* among others.
The methane yield from anaerobic digestion of algae directly depends on their composition and organic content in particular. However, a positive energy balance depends on methane potential of macroalgae that decreases with storage of the material as well [53]. In the frame of the project 'Algae for biogas in Central Denmark Region' [59], the biogas potential of relevant species of

Danish algae was studied. Especially the biogas potential of *Laminaria digitata* (oar weed) was found very promising. Methane potential was evaluated after 30, 60 and 90 days (Figure 5).



	Laminaria	Saccharina	Chaetomorpha linum	Aschophyllum	Ulva lactuca	Pilayella littoralis and Ectocarpus siliculosus
90 days	7	2	7	8	24	0
60 days	34	12	18	54	50	1
30 days	257	206	162	119	100	117

Figure 5: Methane potential (after 30, 60 and 90 days, respectively) in different algae species [59]

2.3. Challenges related to cast seaweed management: ecosystem services

Cast seaweed is a resource we receive from the sea. It is expected that any quantity of cast seaweed removed from beaches and used for energy production in the project area can advantageously contribute to a range of achievements such as reduced eutrophication, closing the nutrient cycle, contribute to the transition to the circular bioeconomy, regional development, increased tourism and services, creating local value chains, the security of supply, diversification of the energy system and reduction of greenhouse gas emissions (both from the removal of rotten seaweed and when replacing fossil fuels with biogas and fossil-based synthetic fertiliser with an organic fertiliser).

The UN Millennium Ecosystem Assessment (MEA) [60] focused on the linkages between ecosystems and human well-being and, in particular, on '*ecosystem services*', i.e. the benefits people obtain from ecosystems. Fisher et al. [61] referred to the term popularised by MEA as *ecosystem characteristics* that are actively or passively used to produce human well-being. Marine ecosystem services can be divided into *provisioning*, *supporting*, *regulating* and *cultural services*, following the classification used in [60].

The Baltic Sea provides us with many valuable services including transport, energy, food, mineral resources and recreational facilities. When assessing ecosystem goods and services, we should understand that environmental gains are economic gains too. According to [62], out of 24 marine ecosystem services identified in the Baltic Sea region (listed in Table 3), only 10 are operating properly and seven are under severe threat. This includes the food web, biodiversity, habitats, Baltic Sea resilience (the capacity of the sea to resist and recover from disturbances), food, genetic resources and aesthetic values. Eutrophication together with overfishing have been identified as the main threats to ecosystem services in the Baltic Sea.

Table 3: Ecosystem services provided by the Baltic Sea, with those most severely threatened marked with an asterisk (*) and the well-functioning ones marked with "√" (modified from [63])

Provisioning ecosystem services	Supporting ecosystem services
Food* Inedible goods √ Energy √ Space and waterways √ Chemicals, e.g., blue pharmacy Ornamental resources √ Genetic resources*	Biogeochemical cycles Primary production √ Food web dynamics* Biodiversity* Habitats* Resilience*
Regulating ecosystem services	**Cultural ecosystems services**
Impact on climate and air quality, e.g., absorption of CO_2 √ Sediment retention, e.g., prevention of erosion Reduction of eutrophication, e.g., retention, recycling and removal of nutrients √ Biological regulation, e.g., remedy of perturbations of the ecosystem √ Regulation of pollutants, e.g., by sediment burial of toxins	Recreation Aesthetic value* Science and education √ Cultural heritage Inspiration √ The legacy of the sea

Therefore, cast seaweed management should be carried out in a sustainable manner, i.e. by ensuring the continuing supply of ecosystem services, with respect to ecological, economic, social and technical aspects.

The timely removal of cast seaweed prevents its biodegradation and simultaneously reduces greenhouse gas emissions, otherwise seaweed can float out to deeper water where it could cover bottom fauna, cause oxygen depletion and worsen seawater quality. Removed seaweed will lead to reduction of nutrients (i.e. eutrophication) in the Baltic Sea. Therefore, the listed advantages are expected to lead to a cleaner sea and benefit the entire marine ecosystem.

Improvement of the recreational beaches will enable people to benefit from cultural coastal ecosystem services such as recreation, tourism, aesthetic appreciation, inspiration, a sense of place, and educational value [60]. The recreation and nature-based tourism are important sources of income and contribute to health and social relations dimensions of well-being [60]. Cleaned and aesthetic beaches and cleaner seawater may lead to increased property values in coastal areas as well.

However, if a holistic view is applied to the cast seaweed problem, the role of this biomass in coastal environment should be assessed as well. The cast seaweeds can be incorporated into physical beach processes like dune formation or integrated into terrestrial or marine food webs through consumption and decomposition [64]. The seaweeds can support a diverse ecology of organisms through its nutrient cycling and decomposition including bacteria, yeasts and fungi in the microflora, nematodes, invertebrate larvae and mites in the meiofauna and numerous species of macrofaunal invertebrates of marine and terrestrial origin. It functions as a habitat for invertebrates, serving as prey for predators like shorebirds [65, 66].

Beach cleaning vehicles in the coastal environment have also been recognised as a source of negative impact on coastal ecosystems. The mentioned review [64] has identified a number of key research gaps related to the removal of beach-cast seaweeds from the coastal environment, which include:

- quantitative data on distribution of beach-cast seaweeds;
- relationship between beach-cast seaweed and offshore algal stands;
- residence time of seaweed on the beach;

- fate of seaweeds, when not collected and the communities they support;
- role of floating seaweeds;
- effects of removals on the coastal ecosystem and fisheries resources.

Therefore, the whole range of consequences related to the planned economic activities has to be assessed in order to avoid the threat of the future uses of the Baltic ecosystem goods and services, otherwise actions to restore ecosystem services may be costly.

2.4. Collection of cast seaweed from the beaches of the Baltic Sea and related problems

According to representatives of the PP countries, there is no systematic data on national scale about cast seaweed management – neither in the South Baltic Sea region nor in the whole Baltic Sea region. There are only a few isolated studies in specific seaside municipalities over a certain period of time, where the accumulation of seaweed represents an environmental problem. Available data states that in most cases municipalities are responsible for the removal (or organisation of the removal) of cast seaweed together with other debris found on beaches.

Since the flat and sandy beaches are of the most interest for recreational areas in seaside municipalities and are more easily accessible by cleaning machines, the beach cleaning is organised mostly on this kind of beaches. Availability and accuracy of related information in PP countries differ.

In the South Baltic Sea region, a 1,962 km long coastline belongs to **Denmark.** A number of beaches are being cleaned, but only cast seaweed from 4 km of sandy beach in Solrød is utilised in a biogas plant [67]. **Germany** has 350 km of managed beaches [68]. In **Poland**, seaweed can be collected from 440 km, whereas the seaside municipalities of **Lithuania** indicate that all together they take care of 38.7 km long beach (according to local municipalities). It is complicated to get information on the length of **Swedish** coastline where the beaches are cleaned; according to the BUCEFALOS project a study regarding Scania, 35.6 km of beaches are being cleaned from cast seaweed [69].

The collecting period of cast seaweed differs in countries or even in municipalities within a country. The appearance of the seaweed depends on the temperature, intensity of sunlight as well as the direction of currents and winds. In **Denmark**, cast seaweed is being collected from the beginning of April until the end of September or longer, depending on the weather. In **Germany**, during the touristic season (May until September), cast seaweed is being collected in the early morning hours (between 4 and 9 am). Some municipalities clean the beaches every morning during the summer months, others once or twice a week according to the cast seaweed amount. The main season for seaweed occurrence starts in August but strongly depends on wind and current. In **Lithuania**, in Palanga municipality, which has the longest supervised recreational area, cast seaweed is being removed from April until November. Here, in the beginning of the spring season beach cleaning is obligatory; however, the largest amounts of seaweed are washed ashore during storms regardless of the season. In Neringa, cast seaweed is collected from June until September (and occasionally when needed), whereas in Klaipėda municipality, seaweed on beaches is not collected. In **Poland**, the algae are usually being removed between May and October. In **Sweden**, the collecting period starts on May 15 and lasts until September 15. Seaweed collection is performed with different intensities. All beaches undergo a "spring cleaning" when the bathing season begins, after which some beaches are cleaned daily while others are cleaned a few times a season.

Looking for a possibility to use marine biomass for renewable energy production, the period of cast seaweed collection may be extended. Collection could be performed during winter and spring when storms are more frequent.

Seaweed collection is performed in different ways. Some techniques are already approved for this purpose, others are still tested. The challenge for selecting techniques is to have as low sand content as possible in removed seaweed on one hand (especially, if the material is to be used in a biogas plant) and with minimal impact on coastal nature on the other hand. More details about the seaweed collection methods are given in the COASTAL Biogas project report "A report on operating biogas facilities utilising anaerobic digestion of cast seaweed". The currently used method in Solrød municipality (located in Køge bay), **Denmark**, is to rake the cast seaweed from the beach using front loaders, followed by collection of the material using a beach cleaner. In Solrød, the seaweed is transported directly from the beach to the biogas plant (about 7.5 km). The rest of Køge bay have their own methods: (i) the seaweed is collected from the beach and low water and put into piles, (ii) in the piles the water is reduced, (iii) the seaweed is loaded onto a truck. However, if the sand content is visibly high, the seaweed is dumped into the water, where it is either rinsed and comes back to the beach, where it is now possible to collect and put into piles, or the seaweed is taken by the currents and transported away from the beach. Some municipalities use a temporary storage for the seaweed, later they can use it as fertiliser or push it back into the water when the currents have changed. In **Germany**, collection techniques vary in different municipalities, but mostly collection is done with wheel loaders (Figure 6a) or quad bikes/dune buggies. Then, the material is transported to a (short-term) storage location. Transportation distance and storage methods vary in municipalities. Seaweed is mainly composted and used as fertiliser or disposed of in landfills. In **Lithuania**, in summer of 2019, a modern beach cleaner "BeachTech Marina" (Figure 6b) was purchased by Palanga municipality. It is a compact tractor and beach cleaner all in one enabling to collect small to medium size debris, including seaweed, to a depth of 10 cm on the beach shore. Palanga municipality transports the gathered seaweed to a green waste collection site (in less than 30 km distance), where this material is composted together with other biodegradable waste. Neringa municipality is transporting seaweed to composting site or regional dumping site. In **Poland**, seaweed is removed mainly with a grip-claw loader (Figure 6c) from shallow water. Currently, cast seaweed is collected from all the cities' beaches exclusively for clearing them. After collection from the beaches, the seaweed is transported to waste treatment plants together with all other wastes collected. In **Sweden**, on the beaches of Trelleborg Municipality, the seaweed is picked up using a grid bucket method (a tractor with a fork in the form of rake) and normally stored outdoors in a pile and then returned to the beach after the beach cleaning period (typically May – September).


(a)


(b)


(c)

Figure 6: (a) wheel loader [70]; (b) BeachTech Marina [71]; (c) grip claw loader [72]

The good practice guide for management, collection and treatment of algae and marine plant debris on beaches, prepared in the frame of the SEA-MATTER project (Spain) [73], indicates that the removal of 1000 m³ of debris represents a loss of 19-44 m³ of sediment. The following recommendations that can be useful for the COASTAL Biogas project are proposed in the guide:

- the impact of cleaning operations can be reduced by using machinery with claws to enable the sediment contained in the debris to percolate through and ensure that most of the sand will remain at the beach;
- the use of heavy machinery should be limited and regulated in order to minimise the impact on the morphology of the beach;
- mechanical cleaning should only be performed if the surface (depth of 7-10 cm) is dry;

on beaches with dunes, areas near the dunes (3-5 m) should be left for manual and selective cleaning only.

3. Quantitative potential of cast seaweed

3.1. Available data on potential cast seaweed quantities in the project countries

There is limited data available in regard to the amount of seaweed cast on the coasts of the Southern Baltic Sea. The existing figures usually refer to some specific coastal municipalities. However, locally identified amounts may be extrapolated, if managed coastal length is known.

In **Denmark**, the study [74] of utilisation of cast seaweed combined with waste from pectin production for anaerobic digestion performed in Solrød municipality stated that along the 3.7 km long coastline of this municipality 4,000 tonnes of marine biomass corresponding to 1,081 tonnes per km were collected in 2009.

In **Germany**, an average annual amount of collected seaweed of 50 tonnes per km coastline is given by State parliament of Mecklenburg-Western Pomerania [68]. That gives a potential quantity of 17,500 tonnes of cast seaweed per year for the length of managed beaches (350 km in Mecklenburg-Western Pomerania).

In **Lithuania**, according to data of Palanga municipality, 50 tonnes of seaweed were collected from the beach in 2018. As the length of a supervised coastline is 25 km, an average amount of collected seaweed is 2 tonnes per km coastline during the recreational season. However, some information found online states that in 2010 over 400 tonnes of seaweed were removed from the approximately 1 km long Palanga beach section [75].

In **Poland**, according to the Municipal Sport and Recreation Centre in Gdańsk, it is possible to collect 180-795 tonnes of fresh biomass per season from the beaches of Tricity (Gdańsk, Sopot and Gdynia). In the WAB (Wetland Algae Biogas) project, an average of three years has been used, i.e. 550 tonnes/season. Nevertheless, a maximum amount of 1,500 tonnes could have been collected (if it was needed) in the summer of 2011 [76]. According to the WAB project partners, it can be estimated that about 9,500 tonnes/year of seaweed can be collected from all Polish beaches.

In **Sweden**, the potential for cast seaweed in Scania (the southernmost province in Sweden) was estimated to 83,106 tonnes/year, or rather 63,628 tonnes/year when excluding nature reserves and natural parks [69]. This assessment was performed using extrapolation of existing data, because not every municipality had available data.

3.2. Potential amounts of cast seaweed in the project countries

The quantitative potential of cast seaweed was evaluated for the coastline of the countries of project partners in the territory of the Interreg South Baltic Programme (Table 4). The actual amounts of cast seaweed in tonnes per year (t/a) were obtained from seaside municipalities, scientific studies, information from the project partners and media. The collected information about seaweed quantity was recalculated into equal units such as tonnes per kilometre per year (t/km/a). For the estimation of theoretical potential of cast seaweed, two types of coastlines were selected, i.e. coastline including protected areas (PA) and coastline without them. The coastline itself was indicated from the official sources (information from the project partners) or calculated using ArcGIS tools.

Table 4: Amount of cast seaweed in the project countries in the territory of Interreg South Baltic Programme (PA = protected areas)

Country	Scale	Available annual data (t/a)	Seaweed amount (t/km/a)	Coastline with/without PA (km)	Theoretical potential of seaweed (with PA) (t/a)	Theoretical potential of seaweed (without PA) (t/a)
Denmark	Solrød municipality (3.7 km) [a]	1,500 [a] Up to 4,000 (2009) [a]	405 1081			
	Køge Bay (38.6 km) [a]	7,000 [b]	181			
	Country [b]		4-500 [b]		1,200,000 [b]	420,000 [b]
	Country		405	1,962/1,611 [b]	795,000*	652,000*
Germany	Managed beaches (350 km) [c]	17,500 [c]†	50 [c]†			
	Country		50 [c]†	377/306 [c]†	19,000*†	15,300*†
Lithuania	Palanga municipality (25 km) [d]	50 (2018) [d]	2 Up to 400 (2010) [e]			
	Country		2	95/27 [f]	190*	54*
Poland	Sopot (4.5 km) [g]	400 (2011) [g]†	88†			
	Gulf of Gdansk (~150 km) [g]	800-1000 [h]				
	Country		22 [i]	770/440 [i]	17,000 [i]	9,500 [i]
Sweden	Trelleborg coast (Stavsten-Skateholm) (17 km) [j]	10,500 [j]	617			
	Scania 35.6 km [k]	21,902 (2014) [k]	615		83,100 [k]	63,600 [k]
	Country		615	1,590/960 [f]	978,000*	590,000*
PROJECT AREA				**4,794/3,344**	**1,809,190***	**1,266,854***

[a] [74]; [b] Project partner data (Denmark); [c] [68]; [d] Data from Palanga municipality; [e] [75]; [f] GIS data; [g] [77]; [h] [76]; [i] Project partner data (Poland); [j] [53]; [k] [69]; * COASTAL Biogas; † Not specified but assumed to be fresh weight

Therefore, given available data, a theoretical annual potential of cast seaweed in the project countries (in the territory of the Interreg South Baltic Programme) is estimated at over 1.2 million tonnes of fresh weight. This amount may reach 1.8 million tonnes if protected areas would be included. Such an assessment is approximate and has its shortcomings. The estimation of cast seaweed amounts is limited by the lack of information on the national level since the actual figures usually refer to some specific coastal municipalities and certain periods. Moreover, often the available data vary in different locations of a particular country. Although locally identified averaged amounts may be extrapolated, the problem is to identify the correct length of the PP country coastline that belongs to the South Baltic Sea region and is suitable (in respect of shore type, accessibility, protection areas) for cast seaweed removal.

The main difficulties related to successful cast seaweed management occur during its removal, transportation and disposal. Unfortunately, this biofuel resource is highly unpredictable in time and space: amounts vary from year to year, depending on weather conditions. Wind and its direction determine where and how much seaweed will be washed ashore. The removal of algae from the beaches has to be carried out promptly. The natural leakage of methane is prevented if the seaweed is removed before its decomposition on the beach begins. A timely removal of cast seaweed also prevents its drifting out back to deeper water. Regular beach cleansing all year round could increase the potential amount of seaweed.

However, if the collected algae are to be used for anaerobic digestion, they must be not only fresh but also clear of sand and debris. In Germany, a big challenge is the short period available for cast seaweed collection (3-5 hours in the morning before tourists come to the beaches) in the summer months. Therefore, municipalities/cleaning/utility companies need quick collection methods and a (short-term) storage location in short distance to the beach. Furthermore, with the seaweed a huge amount of sand is being collected, which needs to be separated and returned back to the beach. The sand content of the collected seaweed varies greatly depending on the collection methods, retention time of the seaweed on the beach and the sandy beach properties [78]. The WAB project also revealed that sand levels depend on collecting techniques employed.
Transportation of the collected material to storing or treatment sites is also an important issue. According to the WAB project findings, substrates located farther than 30 km from the biogas plant are unprofitable due to transportation costs. The use of locally available biomass should be encouraged.
Digested biomass from the biogas plant can be used as a fertiliser to substitute chemical fertilisers used on farmlands. In order to use cast seaweed for this purpose it should not exceed the given thresholds for heavy metal contents. To ensure sufficiently low levels of heavy metals, analyses of the marine biomass are necessary.

4. Review of cast seaweed policy frameworks applied in the South Baltic Sea region

4.1. Policy frameworks regarding coastline nature, including nature & coastal protection

EU **Water Framework Directive** 2000/60/EC (WFD) [79], the most substantial piece of water legislation in EU, incorporates the water quality standards and integrates the principles of effective and sustainable development (environmental, economic and social). Eutrophication of coastal waters (which is directly related to cast seaweed problem) is mainly caused by nutrients that come from inland, namely via rivers. The WFD states that an effective and coherent water policy must take account of the vulnerability of aquatic ecosystems located near the coast, as their equilibrium is strongly influenced by the quality of inland waters flowing into them. A necessity to further integrate protection and sustainable management of water into other community policy areas, such as energy, agriculture, tourism, etc., is also highlighted. In the WFD, macroalgae (a component of seaweed) are defined as a biological quality element describing ecological status in coastal waters. If the growing conditions of macroalgae are disturbed (mostly during storms), algae that are detached from the sea bottom will be washed up on the beaches. By using cast seaweed as a substrate and utilising the digestate as a fertiliser, nutrients may be physically removed from the Baltic Sea and hence, provide a powerful tool to mitigate eutrophication. Additionally, this could also move towards cleaner and more attractive beaches for tourists. Therefore, the appropriate seaweed management strongly complies with one of the aims of the Water Framework Directive: it contributes to protection and enhancement of the status of aquatic ecosystems.
The **Marine Strategy Framework Directive** 2008/56/EC [80], a framework within which member states shall take the necessary measures to achieve or maintain good environmental status in the marine environment, was established. In ANNEX I of the Directive qualitative descriptors for determining good environmental status are listed - among them: “Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters”. In ANNEX III,

information on macroalgae as biological feature, including species composition, biomass and annual/seasonal variability, is presented as well. The Directive enshrines in a legislative framework the ecosystem approach to the management of human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use. In order to achieve good environmental status, each member state is required to develop a strategy for its marine waters (or Marine Strategy).

About four decades ago, in 1974, to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental cooperation, **Baltic Marine Environment Protection Commission** (also known as Helsinki Commission - **HELCOM**) was established. Decisions taken by HELCOM are regarded as recommendations and are intended to be incorporated into the national legislation of the contracting parties. HELCOM strives to achieve the **Baltic Sea Action Plan** [81] goal of the Baltic Sea being unaffected by eutrophication. Therefore, the objectives of the COASTAL Biogas project are closely in line with the challenges identified by HELCOM.

In 2009, the European Council approved the **European Union Strategy for the Baltic Sea Region** (EUSBSR) [82]. The Strategy is divided into three objectives, which represent the three key challenges: saving the sea, connecting the region and increasing prosperity. Each objective relates to a wide range of policies and has an impact on the other objectives. Among EUSBSR achievements the support for new projects, including cooperation between farmers to reduce eutrophication is included. All COASTAL Biogas project countries are involved in EUSBSR. For example, in 2010, Lithuanian Government has approved the Baltic Sea Environmental Strategy, which combines several internationally adopted and mentioned above strategic documents: the Helsinki Commission (HELCOM) Baltic Sea Action Plan, the EU Marine Strategy Framework Directive and the EU Strategy for the Baltic Sea Region. According to the established joint work plan, by July 2012 the initial assessment of the state of the Baltic Sea environment was carried out, the characteristics of good environmental status as well as the objectives and indicators to be achieved were determined. In 2014, the State Environmental Monitoring Program has been updated and, in 2015, the Environmental Strategy for Marine Waters under Lithuanian jurisdiction was prepared. By 2016, implementation of the Marine Environment Protection Program was planned.

One of the key instruments in the fight against eutrophication and for the protection of waters against agricultural pressures is the **Nitrates Directive** 91/676/EEC [83]. However, Nitrates directive implementation report (2018) [84] admits that despite some positive progress, nutrients overload from agriculture continues to be one of the biggest pressures on the aquatic environment. This needs to be addressed in order to achieve the good ecological status of waters as established by the WFD. The project recommendation to use digestate as organic fertiliser as a substitute of synthetic fertilisers could help to reduce nutrients amounts in river basins and the Baltic Sea. Organic fertilisers release their nutrients slowly and therefore, feed plants for a much longer period than industrially produced mineral fertilisers. That prevents plants from being over-fertilised and then nutrients from being leached into water bodies.

The problem of proliferation of macroalgae and/or marine phytoplankton due to marine waters pollution is noted in **Directive** 2006/7/EC [85] concerning the management of bathing water quality (**Bathing Water Directive**). The Directive emphasises that water is a scarce natural resource, the quality of which should be protected, defended, managed and treated as such. When the bathing water profile indicates a tendency for increase of macroalgae and/or marine phytoplankton in coastal waters, investigations shall be undertaken to determine their acceptability, health risks and adequate management measures (i.e. removal of biomass washed ashore) shall be taken.

The **Blue Flag Programme** [86] for beaches and marinas run by the international, non-governmental, non-profit organisation FEE (Foundation for Environmental Education) also promotes sustainable development in freshwater and marine areas. It challenges local authorities and beach operators to achieve high standards in water quality, environmental management, environmental education and safety. Over the years, the Blue Flag has become a highly respected and recognised eco-label working to bring together the tourism and environmental sectors at local, regional and national levels. Most Blue Flag beach criteria are imperative, i.e. the beach must comply with them in order to be awarded Blue Flag accreditation. Criterion 15 requires that the beach and surrounding areas must be clean and maintained at all times. However, the FEE position concerning cast seaweed management is different from the mentioned directives. Information about the management of algal waste and seaweed is referred to in criterion 16, which states that algal vegetation or natural debris must be left on the beach. This criterion regards seaweed and other vegetation/natural debris as natural components of both freshwater and marine ecosystems. These ecosystems must be considered as living and natural environments and not only as a recreational asset to be kept tidy. Thus, the management of seaweed or other vegetation/natural debris on the shore should be sensitive to both visitor needs and biodiversity. Natural disposal by tides and waves at the beach is accepted, as long as it does not create a nuisance. Vegetation should not be allowed to accumulate to the point where it becomes a hazard, however, only if it is absolutely necessary should vegetation be removed. If vegetation is removed, then consideration must be given to its disposal in an environmentally-friendly way, e.g. through composting or for fertiliser use (the utilisation through anaerobic digestion can also be considered environmentally-friendly). It is recommended that not 100% of the seaweed is removed, and that removal should focus on the areas where the accumulation creates problems. However, there is no specific legislation regarding the removal of waste from beaches that do not meet Blue Flag standards, and each member state of the EU applies their own regulations regarding solid waste collection as well as cast seaweed management.

Adopted in 1992, the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (**Habitats Directive**) [87] aims at promoting the maintenance of biodiversity, taking economic, social, cultural and regional requirements into account. It forms the cornerstone of Europe's nature conservation policy together with the **Birds Directive** [88] and establishes the EU wide **Natura 2000** ecological network [89] of protected areas, safeguarded against potentially damaging developments. The aim of this directive shall be to contribute towards ensuring biodiversity through the conservation of natural habitats and of wild fauna and flora in the European territory of the member states to which the Treaty applies. There are about 230 different types of natural habitats listed in Annex I ‘Natural habitat types of community interest whose conservation requires the designation of special areas of conservation’ (Natura 2000). Therefore, it is required to declare certain areas as protected and to establish measures to achieve a good conservation status of these protected areas. Ten different types of these habitats are reported as marine habitats for reporting purposes (Table 5). Some of these habitats exist in the coastal area, while others are present in shallow and deeper areas of the sea and they can be affected by the economic activities. The **Habitats Directive** requires EU members to establish a network of safety measures for certain marine species, including seaweed.

Table 5: Types of natural habitats of the sea in Natura 2000 Annex I "Natural habitat types of community interest whose conservation requires the designation of special areas of conservation"

Code	Type of habitat
1110	Sandbanks which are slightly covered by sea water all the time
1120	Posidonia
1130	Estuaries
1140	Mudflats and sandflats not covered by seawater at low tide
1150	Coastal lagoons
1160	Large shallow inlets and bays
1170	Reefs
1180	Submarine structures made by leaking gases
1650	Boreal Baltic narrow inlets
8330	Submerged or partially submerged sea caves

Each member state shall propose a list of sites indicating which natural habitat types in Annex I and which species in Annex II are native to the site's territory. There are no macroalgae among the species listed in Annex II. Of the more than 90 species listed in Annex V, two species of red algae *Corallinaceae (Lithothamnium coralloides* and *Phymatolithon calcareum)* are included; member states must ensure that their exploitation and capture in the wild is in a favourable conservation status. According to the project participants, the following national policy frameworks and measures related to the coastline nature are applied.

In Denmark, Natura 2000 [89], the Nature Conservation Act [90], the Danish Marine strategy [91], and Coastal Protection Act [92] are the main policy frameworks applied in regard to the sea coastline nature and coastal protection.

In Germany, coastline and nature protection is described in Federal Nature Conservation Act [93]. As an important habitat and breeding area with feeding and resting opportunities for many species, large sections of the German Baltic coast have conservation status. According to the Flora-Fauna-Habitat Directive (92/43/EEC) [87], there are many protected biotopes. The following numeration shows these special areas of conservation [87, 94]: "seaweed meadows associated" codes of habitat types: 1110, 1130, 1140, 1150, 1160 (also listed in Table 5); "beach associated" habitat types: 1210 (Annual vegetation of drift lines), 2110 (Primary dunes) and 2120 (White dunes with marram grass *(Ammophila arenaria)*). Since flora and fauna of the various biotopes along the coast of the Baltic Sea are threatened by storm surges, erosion, pollution, overfishing and eutrophication, for the preservation of these unique natural spaces, strong coastal protection measures are used [95]. A series of programs of measures and reduction targets for the Baltic Sea were developed in order to implement the requirements of the WFD at federal and state level [96].

In Lithuania, the key principles of and arrangements for the protection of the Baltic Sea environment are provided by the Law on the protection of the marine environment [97]. The Baltic Sea Environmental Strategy [98] was approved in 2010, and it combines internationally adopted and mentioned above strategic documents. Lithuanian coastline of approx. 68 km belongs to Seaside Regional Park, Curonian Spit National Park and other protected areas within which Natura 2000 territories are located. The Baltic Sea coastline of Lithuania is classified as a Reef habitat (code 1170), but any prohibitions on the coast (e.g. seaweed cleaning) related to this habitat are not applied. The other two marine habitats located in Lithuanian seaside are Estuaries (1130) and Coastal lagoons (1150). Each coastal municipality has its own rules and regulations describing the management of municipal beach and bathing area management as well as safety issues. However, all of them follow Lithuanian hygiene standard concerning beaches and bathing water quality [99] approved by the Order of the Minister of Health. This document requires monitoring of macro-algae and (or) phytoplankton on the beaches and bathing areas. In case of their spread, it is necessary to determine the health risk and to remove accumulated cast seaweed from the beaches. It also obliges to remove waste and algae from bathing areas after storms. However, until now, no legal acts are available describing the further fate of the collected biomass and the responsibility of its disposal or utilisation lies with the municipalities.

In Poland, a large part of the coastal area is located in the protected area Natura 2000. The legal act regulating the functioning of the Natura 2000 network in Poland is the Nature Protection Act [100]. According to this act, the Natura 2000 does not apply any specific list of prohibitions. There is only one general prohibition of actions that may, individually or in combination with other activities, have a significant negative impact on the conservation objectives of the Natura 2000 site.

Normally, **in Sweden**, without the permission from the county administrative board it is not allowed to clear seaweed in nature reserves or national parks, but in some cases permission is granted. In Vellinge municipality in Scania, all the beaches are within nature reserve, but Vellinge municipality is allowed to clean the beaches anyway.

4.2. Policy frameworks regarding use of seaweed as a potential feedstock for 'green energy' production

Directive 2008/98/EC (**Waste Framework Directive**) [101] and its updated version Directive (EU) 2018/851 [102] provide a general framework for regulation of waste management and basic definitions regarding waste management for all EU members. This directive clarifies that recovery operation of solid waste should be energy-efficient in any case of its usage. Consequently, the directive defines basic principles about how the waste legislation should be applied in a generally accepted manner and highlights the priority order of implementation steps. The hierarchy of waste prevention and management in EU legislation and policy of the mentioned directive is listed as follows: prevention, preparation for re-use, recycling, other recovery (e.g. energy recovery) and disposal (Figure 7).

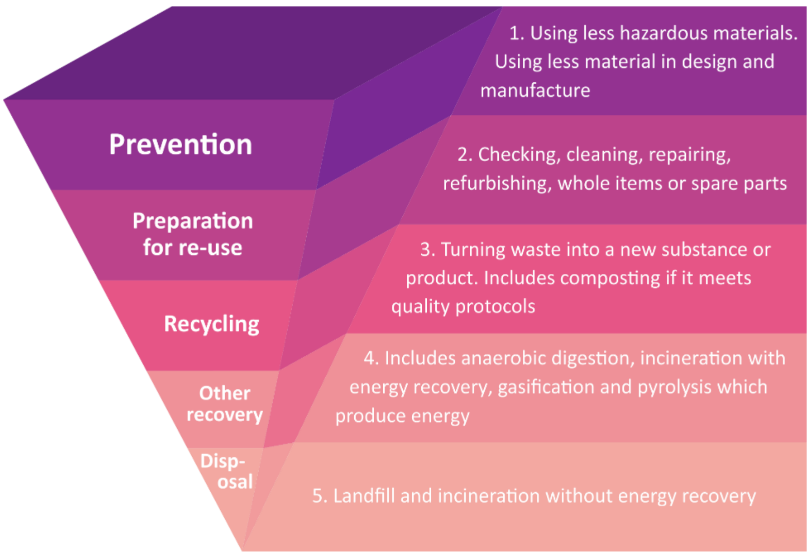


Figure 7: The hierarchy of waste prevention and management in EU legislation and policy of Waste Framework Directive

In terms of cast seaweed, the prevention means to take measures before a substance or amounts of material become waste. The reduction of waste quantity, including the re-use of products, becomes the main priority, because accumulated biomass of cast seaweed can cause significant impact on the social environment and human health. If the content of harmful substances in accumulated materials is dominant, environmental impact should be considered as well.

As the second priority of the **Waste Framework Directive**, the re-use is distinguished. It means that any operation by which products or components are not considered as waste should be used again. However, in case of seaweed, the cast material should be prepared for re-use and according to the directive this definition means checking, cleaning or repairing recovery operations. During the mentioned operations the products or components of products that have become waste are prepared and they can be re-used without any other pre-processing. However, the analysed priority of the directive does not include re-use for energy production.

The definition of recycling cannot be applied for the treatment of cast seaweed, because this process means any recovery operation by which waste materials are re-processed into products, materials or substances for the original or other purposes. It includes the re-processing of organic material but does not include energy recovery and the re-processing into materials, which will be used as fuel or for backfilling operations.

The closest priority of waste management for useful utilisation of cast seaweed is linked to the definition of 'other recovery'. The principal result of the mentioned operation is waste serving a useful purpose that can fulfil a particular function (e.g. energy production). Secondary, the cast seaweed would be prepared to fulfil the priority of 'other recovery' in the biogas plant (or in the wider economy such as recovery operations), where seaweed would be used principally as a substance for fuel (biogas) or other means to generate energy.

All disposal and recycling works of bio-waste including actions of seaweed treatments in community states must follow general requirements of Directive 2008/98/EC. Here, the separate collection of bio-waste regarding the composting and digestion of bio-waste are highlighted as priority statements, as well as the treatment of bio-waste in a way that fulfils a high level of environmental protection. The management of bio-waste requires to carry out a wider assessment on possible impacts in submitting a proposal if appropriate. The assessment should examine the opportunity of setting minimum requirements for bio-waste management and quality criteria for compost and digestate from bio-waste, in order to guarantee a high level of protection for human health and the environment.

The permits and registrations defined in Directive 2008/98/EC provide following guidelines for implementation of secondary usage of bio-waste:

- the types and quantities of waste that may be treated;
- for each type of operation permitted, the technical and any other requirements relevant to the site concerned;
- the safety and precautionary measures to be taken;
- the method to be used for each type of operation;
- such monitoring and control operations as may be necessary;
- such closure and after-care provisions as may be necessary.

These kinds of permits may be granted for a specified period and may be renewable if required. In the case where the competent authority considers that the intended method of treatment is unacceptable from the point of view of environmental protection and/or human health, it shall refuse to issue the permit. Whereas in the first place, it must satisfy the requirements for human health and environmental protection, which concentrate on clean conditions of water, air, soil, plants and animals without causing a nuisance through noise or odours. The impact on the

countryside or places of special interest is subordinate. Especially previously mentioned points are important in establishing biogas plants because the condition of any permit related to the incineration with energy recovery requires a high level of energy efficiency in energy recovery.
Directive (EU) 2018/850 on the landfill of waste (**Landfill Directive**) [103] as an expanded version of Directive 1999/31/EC on the landfill of waste [104] claims general requirements for all classes of landfills, where the gas control is particularly important. The directive defines that landfill gas shall be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and utilised. If the gas collected cannot be used to produce energy, it must be flared. Therefore, if cast seaweed is utilised in form of waste storage, the highest level of protection control regarding gas release must be maintained. In the best case scenario, the gases should be collected and used in most efficient ways of energy production for further steps.
Historically **in Denmark**, seaweed has been used - in limited quantities - as compost, soil cover material and for cultivation. The purpose has been to supply the soil with the necessary macro- and micronutrients. Like other types of compost, seaweed has the effect of making the soil rich in humus and easier to cultivate. If the seaweed is used on agricultural and cultivated land, it must comply with a number of limit values (Table 6) in accordance with the **Danish Waste to Soil Regulation** [105] (formerly known as the **Statutory Order on Sludge**).

Table 6: The limit values of different components found in cast seaweed

Components	Daily threshold [mg/kg DM]
Cadmium	0.8
Mercury	0.8
Lead	120
Nickel	30
Chromium	100
Zinc	4000
Copper	1000
LAS	1300
PAH	3
NPE	10
DEHP	50

The use of seaweed in a biogas plant is subject to the same rules. Since the seaweed after degassing in the biogas plant must be spread on agricultural land together with the other raw materials, it is required that the seaweed at the entrance to the biogas plant complies with the limit values of the mentioned regulation. On the basis of the mentioned rules, before the seaweed collection is started, it is required by Solrød Biogas plant that the samples of the seaweed material are taken and analysed by an accredited research agency (Eurofins). It must be analysed for inorganic compounds (nitrogen, phosphorus, chloride), metals, detergents, PAH compounds, plasticisers and phenols. If the limit values for one of the analysed substances are exceeded, the seaweed must not be brought to Solrød Biogas plant.
In addition to the requirements in the **Waste to Soil**, there are further demands on the seaweed deposited at the biogas plant, namely the following requirements: (1) there shall be minimal sand in the seaweed that is being delivered (use of Best Available Technology); (2) visible fractions of plastic and metal in the seaweed are not allowed; (3) large stones in the seaweed are not allowed and (4) the sand content may not exceed 60% of dry matter.

In Germany, cast seaweed is categorised as bio-waste (waste code 20 02 01; biodegradable wastes). The **Bio-waste Ordinance** [106], applicable on seaweed, states that it has to be composted or treated in a biogas plant before the utilisation on farmland. A maximum of 20 or 30 tonnes dry matter (DM) of bio-waste can be applied per hectare within three years when contamination with heavy metals does not exceed given thresholds (see Table 7).

Table 7: Thresholds for heavy metals in bio-waste applied on agricultural land according to the Bio-waste Ordinance §§ 4 and 6

Heavy metal	Threshold [mg/kg DM] when applying 20 t DM/ha in 3 years	Threshold [mg/kg DM] when applying 30 t DM/ha in 3 years
Lead	150	100
Cadmium	1.5	1.0
Chromium	100	70
Copper	100	70
Nickel	50	35
Mercury	1.0	0.7
Zinc	400	300

Additionally, the **Fertiliser Ordinance** [107] is applicable in case the cast seaweed will be applied on farmland. The material has to be checked for hygiene, contaminants and foreign substances (salt content, pH-value, concentration of organic substance, dry residue, content of foreign substances and stones). In accordance with mentioned regulations, no landfill of fermentation residues from biogas plants, in which only conventional substrates are fermented, is permitted on areas of organic farming. Accordingly, only such areas of conventional agriculture are available for using digestate as fertiliser.

In Lithuania and **Poland**, at the current time, there are no regulations regarding the use of seaweed for green energy production.

In Sweden, to be able to use the digestate as bio-fertiliser, it has to be certified (SPCR 120) [108]. Substrates that can be used are listed on the 'positive list', but seaweed is currently not included. To be included, one has to apply for it and show the characteristics of the substrate in terms of contaminants, heavy metal content etc. There are limit values for the digestate containing metals, e.g. 1 mg Cd/kg dry matter.

4.3. Regulations on biogas plant establishment

The establishment of biogas plants requires an accurate understanding of legislation at the national and European Union (EU) scale. Therefore, the successful implementation of biogas plants highly depends on the strictness of the law. It must comply with a number of different regulations, such as the development of renewable energy sources, waste storage and management, efficient energy production, prevention and control of integrated pollution, sustainable water use, etc. The EU directives are the primary documents, which provide an understanding of how different anthropogenic activities should be managed towards human and environmental well-being and sustainable development. Also, the directives ensure that all members will include the recommendations and regulations to their national legislation documents. In Table 8, the fundamentals of general policy knowledge for the unification of the common regulations for the implementation of biogas plants in all EU member states and the description of each EU directive are summarised.

Table 8: Compilation of EU Legislation Framework related to the Implementation of biogas plants

Document	Description
Directive 2009/28/EC Promotion and production of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC [109]	In this directive, an overall policy for the production and promotion of energy from renewable sources in the EU is established. It provides the framework in which all member states may set their national plans for increasing the use of Renewable Energy Sources (RES) in order to meet the energy targets of the European Union. Also, this directive establishes a legislative common framework for the use of energy from renewable sources in order to limit greenhouse gas emissions to promote cleaner transport.
Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources [110]	The revised renewable energy directive 2018/2001/EU entered into force, as part of the 'Clean Energy for all Europeans' package, aimed at keeping the EU a global leader in renewables and, more broadly, helping the EU to meet its emissions reduction commitments under the Paris Agreement. The new directive establishes a new binding renewable energy target for the EU for 2030 of at least 32%.
Directive 2008/98/EC Wastes [101]	This directive sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling and recovery. It explains under which circumstances waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products. In the directive, some basic waste management principles are laid down. One example is that waste requires being managed without endangering human health and harming the environment (without risk to water, air, soil, plants or animals; without causing a nuisance through noise or odours; and without adversely affecting the countryside or places of special interest).
Directive (EU) 2018/851 amending Directive 2008/98/EC on waste [102]	Directive (EU) 2018/851 requires member states to improve their waste management systems into the management of sustainable material, to improve the efficiency of resource use and to ensure that waste is valued as a resource. Among other areas of focus, the amendments address: • Measures to prevent waste generation, inter alia, obliging member states to facilitate innovative production, business, and consumption models that reduce the presence of hazardous substances in materials and products, encourage the increase of the lifespan of products, and promote re-use. • The handling of municipal wastes. • Incentives for the application of the waste hierarchy, such as landfill and incineration charges or pay-as-you-throw schemes. • Measures to encourage the development, production, marketing and use of products suitable for multiple use that contain recycled materials and that are, after having become waste, suitable for re-use and recycling. • Measures to promote the re-use of products constituting the main sources of critical raw materials (natural and anthropogenic origin) to prevent those materials from becoming waste. • Minimum operating requirements for extended producer responsibility schemes.

Document	Description
Directive 2012/27/EC Energy Efficiency [111]	This directive establishes a set of binding measures to help the EU reach its 20% energy efficiency target by 2020. This means that overall EU energy consumption should be no more than 1483 million tonnes of oil equivalent (Mtoe) of primary energy or 1086 Mtoe of final energy. Under the directive, all EU countries are required to use energy more efficiently at all stages of the energy chain, including energy generation, transmission, distribution and end-use consumption.
Directive (EU) 2018/2002 amending Directive 2012/27/EU on energy efficiency [112]	Directive (EU) 2018/2002 was agreed to update the policy framework to 2030 and beyond. The key element of the amended directive is a headline energy efficiency target for 2030 of at least 32.5%. The binding target, to be achieved collectively across the EU, is set relative to the 2007 modelling projections for 2030. In absolute terms, this means that EU energy consumption should be no more than 1273 Mtoe of primary energy and/or no more than 956 Mtoe of final energy. The directive allows a possible upward revision in the target in 2023, in case of substantial cost reductions due to economic or technological developments.
Directive 2009/73/EC Rules for the internal market in natural gas [113] **Directive (EU) 2019/692** amending Directive 2009/73/EC concerning common rules for the internal market in natural gas [114]	This directive seeks to address obstacles to the completion of the internal market in natural gas, which result from the non-application of Union market rules to gas transmission lines to and from third countries. The amendments introduced by this directive are intended to ensure that the rules applicable to gas transmission lines connecting two or more member states are also applicable, within the Union, to gas transmission lines to and from third countries. This will establish consistency of the legal framework within the Union while avoiding distortion of competition in the internal energy market in the Union and negative impacts on the security of supply. It will also enhance transparency and provide legal certainty to market participants, in particular investors in gas infrastructure and system users, as regards the applicable legal regime.
Directive 2008/1/EC Integrated pollution prevention and control [115] Repealed by **Directive 2010/75/EU** on industrial emissions [116]	The purpose of this directive is to achieve integrated prevention and control of pollution arising from certain industrial activities (listed in Annex I), including energy and mineral industries, production and processing of metals, chemical industries and waste management.
Directive 2000/60/EC Water Policy [1] **Directive 2014/101/EU** amending Directive 2000/60/EC [117]	This directive establishes a common framework for Community action in the field of water policy, including key instruments in the protection of waters against agricultural pressures related with nitrates.
Directive 1999/31/EC Landfill [104]	The purpose of this directive is to provide measures, procedures and guidance in order to prevent or reduce negative effects on the regional and global environment (the pollution of surface water, groundwater, soil, air and greenhouse effect) as well as any other risk to human health that might result from landfilling of waste.
Directive (EU) 2018/850 amending Directive 1999/31/EC on the landfill of waste [103]	Directive (EU) 2018/850 requires member states to significantly reduce waste disposal by landfilling. This will prevent detrimental consequences for human health and the environment and ensure that economically valuable waste materials are recovered through proper waste management and in line with the waste hierarchy. Member states will be required to ensure that, as of 2030,

	waste suitable for recycling or other recovery, in particular contained in municipal waste, will not be permitted to be disposed of to landfill. Use of landfills should remain exceptional rather than the norm.

In Denmark, the following scheme for regulation on biogas plant implementation has been elaborated (Figure 8):

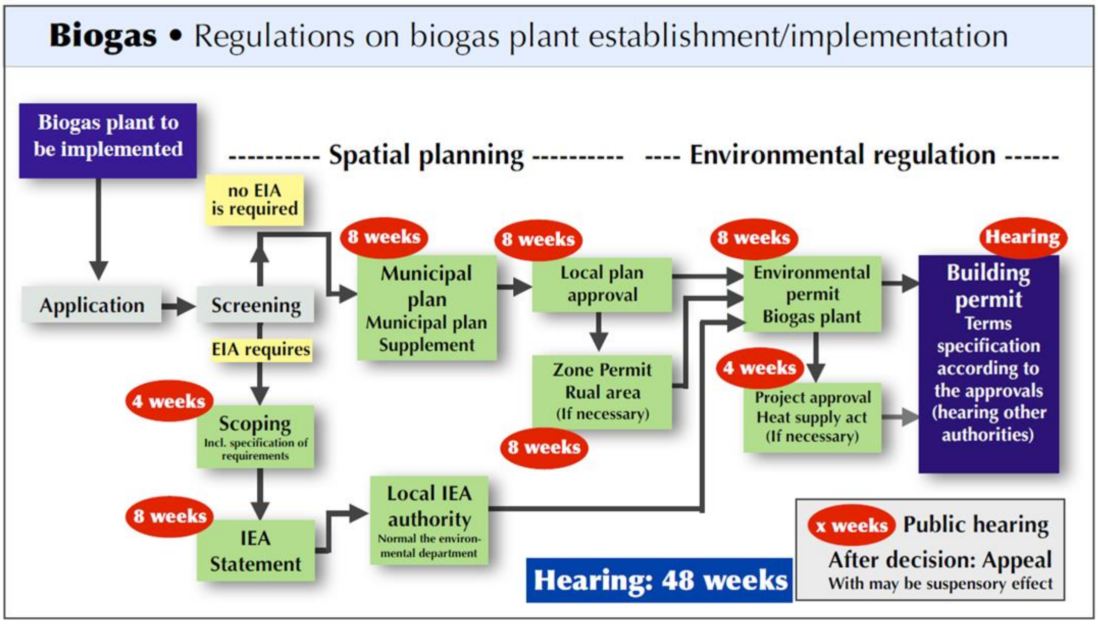


Figure 8: The scheme of regulations on biogas plant establishment applied in Denmark [118]

In Germany (Mecklenburg-Western Pomerania) the Climate Action Plan of March 2010 [119] formulated the targets for the use of bioenergy by the year 2020 [120]. Bioenergy can provide electricity, heat and fuel. As an economical engine for the region, it is very lucrative. The federal states support this development with funding programmes.

In Lithuania, according to the Regulation on environmental impact assessment of the proposed economic activity [121] the establishment of biogas plants requires the screening for environmental impact assessment.

In Poland, according to the Regulation [122] on undertakings that may significantly affect the environment, agricultural biogas plants with an electrical capacity below 500 kW, do not have a significant impact on the environment. Consequently, there is no need to create a report on the environmental impact assessment (Energy Policy of Poland until 2040) [122].

In Sweden, the Environmental Code [123] decides, which types of environmentally hazardous activities require a permit and how to conduct a permit test. Biogas is included in the category of flammable and explosive goods and its management and use has to follow the Flammable and Explosive Goods Law [124]. Other laws that have to be followed when establishing a biogas plant are the Working Environmental Law [125], the Accident Protection Act [126] and the Plan and Buildings Law [127]. To simplify the establishment of a biogas plant, the Swedish Gas Association has compiled the Energy Gas Standards [128] and if they are followed the biogas plant will meet the requirements of the legislation.

Concluding remarks

In the report, the possibilities to collect cast seaweed from the coasts of the South Baltic Sea region were discussed. After producing green energy through anaerobic digestion, this biomass further can be utilised as a valuable biofertiliser, rich in plant nutrients, and substitute industrially produced mineral fertilisers, thus mitigating eutrophication and reducing nutrient loads into the sea. The availability of cast seaweed and its potential amounts in the region were assessed. The estimated theoretical annual potential of cast seaweed within the Programme area exceeds 1.2 million tonnes. This amount would be higher if protected areas were included but this should be carefully considered to prevent potential damage to sensitive ecosystems.

The use of cast seaweed for biogas production poses many regulatory challenges. It requires an accurate understanding of legislation at the national and EU scale. This activity must comply with many different regulations related to coastline nature protection, development of renewable energy sources, waste storage and management, prevention and control of integrated pollution, etc. The review revealed that, to date, in the project partner countries, there are no clear procedure descriptions of the steps in the path of cast seaweed from the beach to biogas plant defined by the national law. This makes it more difficult for biogas plant operators to decide whether to utilise cast seaweed as substrate.

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