Baltic LINes

Coherent Linear Infrastructures in Baltic Maritime Spatial Plans

2030 and 2050 Baltic Sea Energy Scenarios – Ocean Energy

Interreg Baltic Sea Region

EUROPEAN UNION

EUROPEAN REGIONAL DEVELOPMENT FUND

2030 and 2050 Baltic Sea Energy Scenarios

– Ocean Energy

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Summary

The ocean energy and marine bioenergy provides significant opportunities to contribute to the production of low carbon renewable energy around the world. Utilization of resources can contribute to the world's future sustainable energy supply. Ocean energy and marine bioenergy can supply electricity, drinking water and other products at competitive prices, creating jobs and reducing dependence on fossil fuels. It can contribute to reduce the world energy sector's carbon emissions, whilst minimizing impacts on the marine environment.

Baltic Sea is a sheltered sea, but it has been calculated to have an energy potential of 24 TWh that could be used in coastal areas in Baltic Sea countries. In the Baltic Sea area, the wave conditions vary strongly between seasons and areas. The biggest basin of the Baltic Sea, the Baltic Proper, has the most severe wave climate in the Baltic Sea. Ice formation during winter times hinders the wave formation and limits the wave energy production. The choice of suitable kind of technology and adjusting it to local conditions, can give the optimal production of wave energy. There are few things that will to some extent decrease areas possible for exploitation, foremost shipping lanes, important fishing zones and marine protected areas as well as geo-physical conditions. However most likely these wave energy parks would be dispersing and suited with the environment.

Seaweed farming is an environmentally friendly way to produce fuels in the coming years. Researchers are looking to mechanize the process for large-scale seaweed production. They will also have to find cost-effective renewable energy processes for drying seaweed or else the overall costs will shoot up. Success in large-scale production of seaweed-based biofuels would mean reduction of our excessive dependence on oil in the future. Although large-scale seaweed biofuel production is not yet a reality, millions are being invested in seaweed research around the world and there is hope that this novel technology will be widely used for biofuel production in the future. To meet the future demand for liquid fuels the marine areas for production will need to be rather large and probably be combined with large offshore wind parks or other aquaculture activities. In the Baltic Sea, Kattegat and Skagerrak there is little in literature that support a large-scale development and the needs regarding those areas. To get to large scale production extensive research on technologies that will help reducing the overall cost is needed. To test and demonstration of new techniques areas for marine research is a must.

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1 Introduction to Ocean Energy and Marine Bioenergy

The world's oceans and seas contain an enormous untapped energy reserve. Ocean tides, streams and waves have a high energy content support the drive towards renewable energies. So far, mainly river stream energy converters are on a commercial scale while tidal turbines are getting closer to the market. Wave energy will contribute to the energy production first in a longer time frame. Nevertheless, there are some permits given and prototypes in the water.

The ocean energy and marine bioenergy provides significant opportunities to contribute to the production of low carbon renewable energy around the world. Utilization of resources can contribute to the world's future sustainable energy supply. Ocean energy and marine bioenergy can supply electricity, drinking water and other products at competitive prices, creating jobs and reducing dependence on fossil fuels. It can contribute to reduce the world energy sector's carbon emissions, whilst minimizing impacts on the marine environment.

The Ocean Energy Systems (OES) Vision of international deployment of ocean energy estimated a global potential to develop **748 GW** of ocean energy by 2050. Deployment of ocean energy can provide significant benefits in terms of jobs and investments. The global carbon savings achieved through the deployment of ocean energy could also be substantial. By 2050 this level of ocean energy deployment could save up to **5.2 billion tonnes of CO_2.** In Europe, the demand for marine biofuel products in transportation applications is expected to grow at a CAGR of over 12% from 2018 to 2025. High demand for biodiesel in the European countries owing to the government regulations and high adoption rate in the region is expected to propel industry growth.

Electricity is the rising force among worldwide end-uses of energy, making up 40% of the rise in final consumption to 2040 – the same share of growth that oil took for the last twenty-five years. Industrial electric motor systems account for one-third of the increase in power demand in the New Policies Scenario. Rising incomes mean that many millions of households add electrical appliances (with an increasing share of "smart" connected devices) and install cooling systems.

Electricity makes inroads in supplying heat and mobility, alongside growth in its traditional domains, allowing its share of final consumption to rise to nearly a quarter. A strengthening tide of industry initiatives and policy support pushes our projection for the global electric car fleet up to 280 million by 2040, from 2 million today.

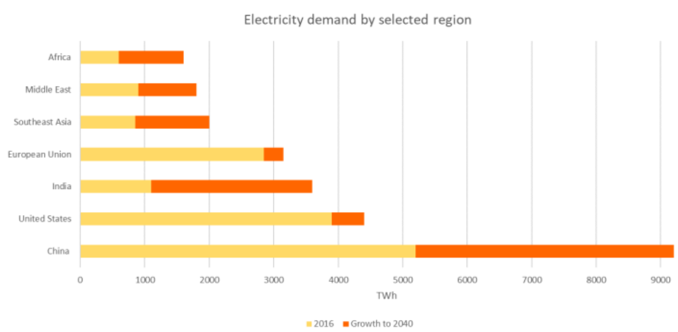


Figure 1 IEA's World Energy Outlook 2017

The scale of future electricity needs and the challenge of decarbonising power supply help to explain why global investment in electricity overtook that of oil and gas for the first time in 2016 and why electricity security is moving firmly up the policy agenda. The increasing use of digital technologies across the economy improves efficiency and facilitates the flexible operation of power systems, but also creates potential new vulnerabilities that need to be addressed. In the European Union, renewables account for 80% of new capacity and wind power becomes the leading source of electricity soon after 2030, due to strong growth both onshore and *offshore*.

The global algae biofuel market is expected to reach USD 10.73 billion by 2025, according to a new report by Grand View Research, Inc. Depleting fossil fuel resources as well as rising awareness towards environment protection is expected to be the key factor for driving industry growth. Algae has the ability to offer 2 to 20 times higher yield than existing biofuel feedstock including corn stover, corn, sorghum and beet which is likely to open new avenues for the industry growth over the projected period. Increasing R&D conducted by numerous start-up companies as well as various oil & gas majors, and university-led research consortiums are expected to propel production of the over the projected period. However, technological challenges and high capital investment in algae biomass and fuel production are expected to limit the industry growth.

Wave Energy Waves are created by the action of wind passing over the surface of the ocean. Wave heights and thus energy is greatest at higher latitudes, where the trade winds blow across large stretches of open ocean and transfer power to the sea swells and west-facing coasts of continents tend to have better wave energy resources. There are number of diverse wave energy converter (WEC) concepts being developed, most of them being intended to be modular and deployed in arrays to capture the kinetic and potential energy from ocean waves and convert it to electricity or pumping water for different uses.

*Tidal energy** is derived by height changes in sea level, caused by the gravitational attraction of the moon, the sun and other astronomical bodies on oceanic water bodies. The potential energy (tidal range) of the difference in the height of water at high and low tides can be captured wit tidal barrages, while the kinetical energy from the moving water of the tide (tidal currents) can also be captured using different tidal current energy converters mainly based on tidal turbines deployed in arrays, similarly to wind farms but underwater.

*Ocean and river currents** are the constant flows of water around the oceans and rivers. These currents always flow in one direction and are driven by wind, water temperature, water salinity and density amongst other factors. They are part of the thermo-haline convection system, which moves water around the world. Similarly, river currents are available in all continents all year long and can be used for energy generation. Both ocean and river current energy technologies are being developed to capture this kinetic energy with most concepts being also based on water turbines deployed in arrays.

Ocean Thermal Energy Conversion (OTEC)* is a marine renewable energy technology that harnesses the solar energy absorbed by the oceans to generate electric power. The sun's heat warms the surface water a lot more than the deep ocean water, which creates the ocean's naturally available temperature gradient, or thermal energy. OTEC uses the ocean's warm surface water with a temperature of around 25°C to vaporize a working fluid, which has a low-boiling point, such as ammonia. The vapor expands and spins a turbine coupled to a generator to produce electricity. The vapor is then cooled by seawater that has been pumped from the deeper ocean layer, where the temperature is about 5°C. That condenses the working fluid back into a liquid, so it can be reused. This is a continuous electricity generating cycle. The energy source of OTEC is free, available abundantly and is continually being replenished if the sun shines and the natural ocean currents exist. Various renowned parties estimate the amount of energy that can be practically harvested to be in the order of 3 to 5 terawatts (1 terawatt is 1012 watts) of baseload power generation, without affecting the temperature of the ocean or the world's environment. That's about twice the global electricity demand. The oceans are thus a vast renewable resource, with the potential to contribute to the future energy mix offering a sustainable electricity production method. The technology is viable primarily in equatorial areas where the year-round temperature differential is at least 20°C.

Salinity Gradient Power* generation is a renewable energy source available 24 hours a day. It is therefore complementary to more variable sources of energy like wind, wave, and solar. Today, the most advanced salinity gradient technology is Reverse ElectroDialysis (RED). With RED, energy can be harvested from the difference in the salt concentration between seawater and fresh water. RED uses stacks of alternating anion and cation exchange membranes to generate electricity. The potential of salinity gradient power is considerable. The energy released from 1 m3 fresh water is comparable to the energy released by the same m3 falling over a height of 260 m. The availability and predictability of salinity gradient energy is very high, and therefore makes it a solid baseload energy source. A pilot plant, powered by FUJIFILM membranes, is currently running in the Netherlands at the Afsluitdijk. Here, seawater of the North Sea meets fresh water of the Ijsselmeer. Further developments to improve the membrane performance (high power density generation) and cost effectiveness are ongoing.

Marine Biomass – The term algae can refer to microalgae, cyanobacteria (the so called "blue-green algae"), and macroalgae (or seaweed). Under certain conditions, some microalgae have the potential to accumulate significant amounts of lipids (more than 50% of their ash-free cell dry weight). These characteristics give great potential for an immediate pathway to high energy density, fungible fuels. These fuels can also be produced using other algae feedstocks and intermediates, including starches and sugars from cyanobacteria and macroalgae. In addition to fungible biofuels, a variety of different biofuels and products can be generated using algae precursors. There are several aspects of algal biofuel production that have combined to capture the interest of researchers and entrepreneurs around the world. These include: 1) high per-acre productivity, 2) non-food-based feedstock resources, 3) use of otherwise non-productive, non-arable land, 4) utilization of a wide variety of water sources (fresh, brackish, saline, marine, produced, and wastewater), 5) production of both biofuels and valuable co-products, and 6) potential recycling of CO2 and other nutrient waste streams.

* This technology is not applicable in the Baltic sea

1.1 What is the challenge?

Ocean energy technologies can contribute to the world's future sustainable energy supply and reduce the dependence on fossil fuels, thereby lowering CO_2 emissions. The challenges facing ocean energy harvesting are similar to those associated with offshore wind power: high costs relative to energy production methods and difficulties related to grid connections, engagement of a dedicated supply chain, and labour and operations in hostile marine environments. Estimation of capital costs (CAPEX) and operating costs (OPEX) remains cumbersome due to the plethora of diverse technologies, most of which are still immature and have not been implemented large-scale or for a sufficiently long time. Consequently, investors and technology developers must extrapolate data from other industries to predict future cost trends, including technology readiness levels and learning curves. More reliable cost information can be derived from studying the likely maturation pathways of currently immature technologies to commercial availability. Another key challenge is to ensure reliability and longevity of the energy converters due to high load cases operating in the sea.

Marine Biofuel - Due to the seasonal dynamics in Scandinavia, the production season is limited by both light and temperature for purely photosynthetic organisms. Realistically, algal production in terms of biomass will not compete with that of warmer regions. Ice cover, another limiting factor to large scale algal production, is highly variable between years and seldom extends to the Baltic proper. On the other hand, ice can be an advantage if biofuels are the focus of the algal feedstock: many "ice algae" or cold temperate algae are naturally very rich in lipids. Numerous claims have been made on the biomass productivity based on small-scale experiments and high value algal products in warm temperate regions. It is necessary to know whether these claims can be extrapolated to large-scale production and to other regions. If one wants to grow algae in the South Baltic region to capture CO_2 produced by industry or local farms, using nutrients from municipal wastewater, for producing feedstock for various energy sources or high value co-products, or a combination of the latter, there are major aspects to bear in mind. The Baltic Sea is an enclosed sea and a very sensitive brackish sea that has been exposed to massive eutrophication, overfishing, pollution and invasive species. It would then be preferable to work with local isolates, not imported or genetically modified ones.

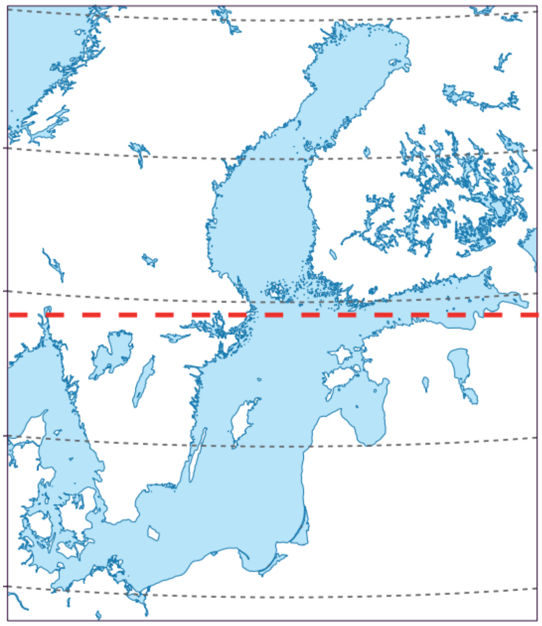


Figure 2 Theoretical upper limit (red line) for algal cultivation

The problem with third-generation biofuels has always been scaling up the production rates measured in small culture flasks to growth in thousands of cubic metres in size. In the larger cultures, the biomass density of the algae – needed to make the culture and harvesting processes economical – defeats desired growth rates because the organisms shade light from each other. This means that they do not get the sunlight needed to photosynthesise and produce the carbon-rich compounds needed for to make the biofuel fast enough. There have also been misunderstandings of how the algae react to their environment. Importantly, those vital carbon-rich compounds only really accumulate in cells that are nitrogen-limited and so are growing slowly. Early production estimates assumed high carbon-rich content in fast-growing cells, but this has not proved to be the case.

2 Ocean energy technologies

The European Marine Energy Center (EMEC) lists over approx. 200 wave energy and almost 100 tidal power developers. Of these, 46 wave and 39 tidal power developers have reached open-water testing. For wave energy, the devices range from small point absorbers deployed in large arrays to multi-body attenuators and large-scale overtopping terminators, all with different methods for energy harvesting. The lack of design consensus hampers the short-term development. As pointed out earlier, the challenges facing ocean energy harvesting are like those for offshore wind power. Another key challenge is to ensure reliability and longevity of the energy converters. The ocean energy industry is actively developing and deploying devices to tap these energy sources as shown below.

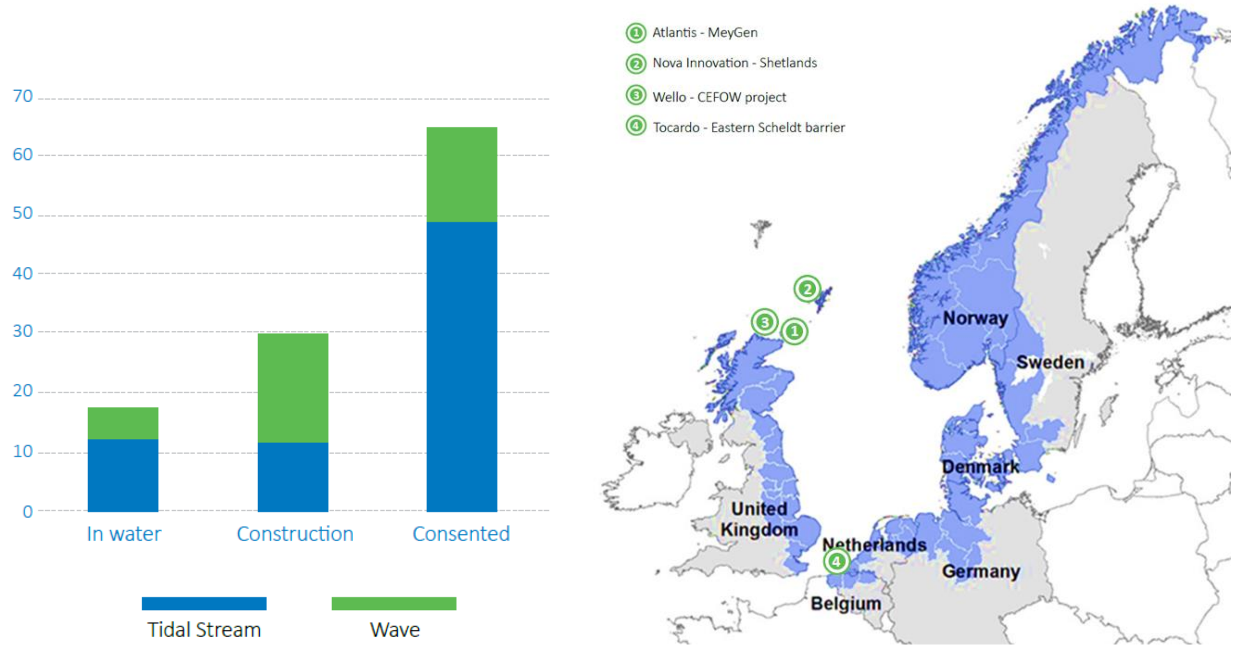
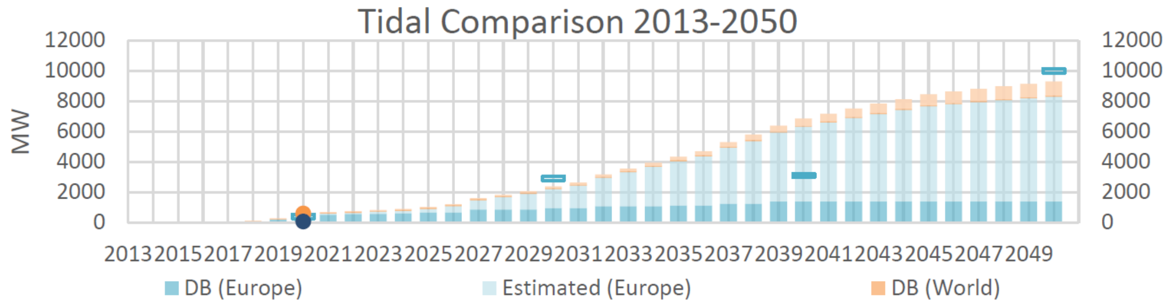


Figure 1: Left: European wave and tidal energy projects in water, under construction, and consented at the end of 2016 ((OEE, 2017)). Right: Spotlight wave and tidal energy projects in the North Sea region, often relating to dedicated test sites (Kafas, et al., 2018)

In European waters, there have been 21 tidal turbines (12MW in total) and 13 wave energy converters (5MW in total) with capacities above 100kW installed and a number more have obtained permit. These devices still must proof reliability, availability and survivability to become commercially viable, certifiable and have a bigger track record to be able to estimate the economic risks related to such projects.

The expected amount of installed capacity spreads significantly and has been compared in a market study from 2018 as shown in the figure below. Not only the volume but even the timing differs significantly from the various sources compared. The potential for these installations is in other waters than the Baltic Sea and the expected installation might take place more wester over in Europe, especially on the Atlantic coast line.



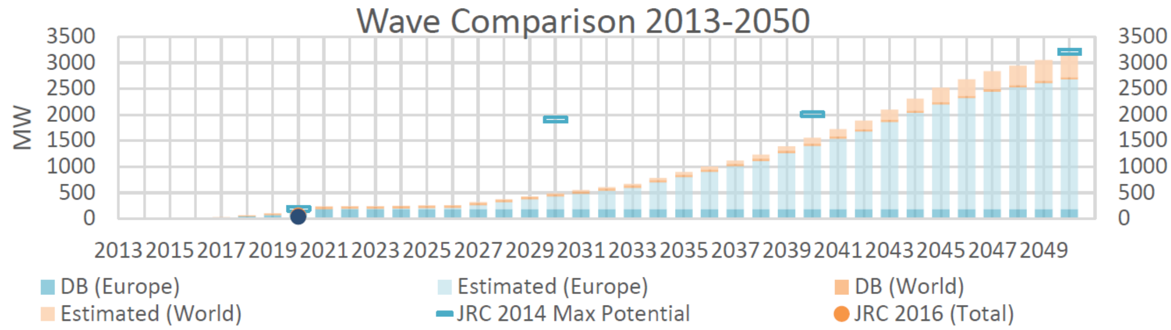


Figure 2: Tidal stream and wave optimistic scenario comparison with published forecasts for 2013-2050 (GUILLOU, 2018), abbreviations indicate different sources of the estimates.

Ocean energy remains a largely untapped renewable energy source, despite decades of development efforts. Of the approximately 529 MW of operating capacity at the end of 2017, more than 90% was represented by two tidal barrage facilities in Korea and France (barrage= an artificial barrier across a river or estuary to generate electricity by tidal power. (Zervos & Adib, 2018). Much of the newly installed capacities are happening around Scotland. The year ended with net capacity additions of at least 4 MW, for a year-end total of 17 MW of tidal stream and 8 MW of wave energy capacity. The first tidal turbine arrays (a cluster of multiple interconnected turbines) were being deployed in 2017. Wave energy converter demonstration projects are mostly in the pre-commercial stage. Developers of ocean thermal energy conversion and salinity gradient technologies are also far from commercial deployment, having launched only a few pilot projects. Challenges to commercial success have included financing obstacles in an industry characterized by relatively high risk and high upfront costs and the need for improved planning, consenting and licensing procedures. A development of these technologies in a larger scale will probably first come into effect after 2030 and the preferred sites will be outside the Baltic Sea.

The installation of ocean energy devices is taking place at a slower pace than expected. Europe only accounts for 14 MW of ocean energy installed capacity at the end of 2016, much lower than the expectation set by Member States in their National Renewable Energy Action Plans. According to NREAPs, 641 MW of ocean energy capacity were expected to be operational by 2016, considering the 240 MW tidal range currently operational in France. By 2020, if technological and financial barriers are overcome, the pipeline of announced European projects could reach 600 MW of tidal stream and 65 MW of wave energy capacity. Considering only projects that have been awarded public funds, 71 MW of tidal stream and 37 MW of wave energy capacity could be operational within the EU in 2020.

One of the key issues that ocean energy developers need to address concerns the reliability and the performances of ocean energy devices; which are designed to operate in demanding environments and the lack of long-term reliability of currently hinders the roll-out of the technologies. Thus far, only few tidal energy devices have proven extensive operational records by employing components largely based on technology employed in the wind energy industry thus benefitting from know-how and knowledge transfer. Critical components and sub-components, such as power take off (PTO), power electronics gearbox and moorings, play a significant role in ensuring overall device reliability. Wave energy designs, however, have not benefitted from such experience and most of the technology developed is still largely unproven and require further R&D, innovation and prototype testing and demonstration to achieve the required levels of reliability.

Another aspect that needs to be considered relates to the survivability of the devices, especially during storms or extreme conditions. Several wave energy devices are being designed to operate in high-resource environments (>50 kW/m), where they will be exposed to strong wave regimes; however most of the deployment thus far have taken place in benign or mild-resource environments. It is therefore necessary that innovative designs and materials are employed to ensure the long-term survivability of devices.

The lack of design consensus among ocean energy devices constitutes a further technological hurdle that the sector should overcome, relating both to overall converters design and to their components. Tidal technologies are showing increasing design and component convergence, with regards to the most advanced prototypes; a commonality which is still not witnessed within the wave energy sector. Achieving design consensus is essential to secure the engagement of the supply chain and unlock cost-reduction mechanisms through economy of scales.

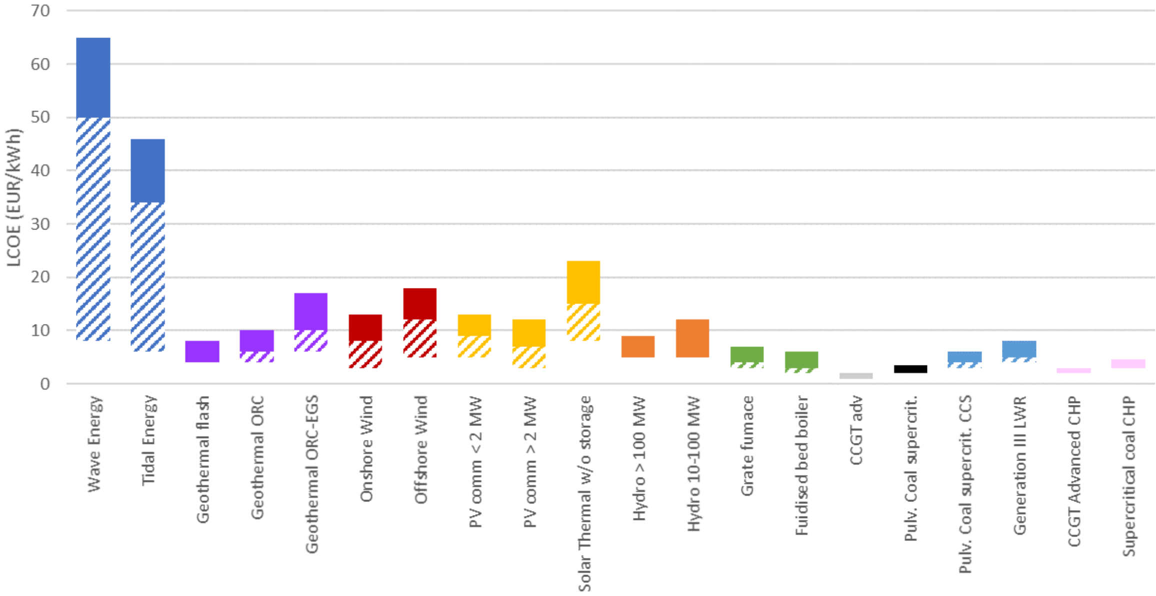


Figure 3 LCOE for different RES

Tidal energy technologies are expected to become commercially viable before wave energy; having shown higher design consensus among them, a more engaged supply chain, and having demonstrated reliability and survivability through extensive testing and operational hours. Existing barriers are daunting the development of ocean energy, whose technologies are currently too expensive and unreliable to compete with other renewable and conventional technologies. Fig. 2 presents and overview of the levelized cost of energy (LCOE) for different energy generating technologies.

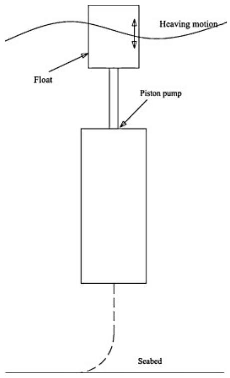
The cost for wave and tidal devices is at the same level as wind was in 1980 (50-60 EUR/kWh). In the longer-term, the European Ocean Energy Forum has suggested, in its ocean energy strategic roadmap, that the cost of energy from wave and tidal farms could tend towards €c10/kWh under the right conditions and through device deployment.

Assuming visibility over significant deployment volumes, the targets are:

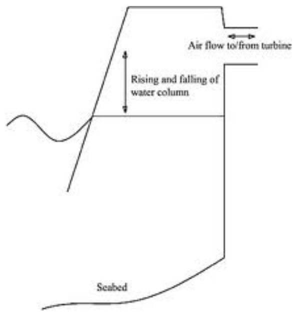
- Tidal Stream – LCoE of €c10/kWh in 2030
- Wave energy – LCoE of €c10/kWh in 2035
- Tidal Range – LCOES of €c13/kW in 2025

2.1 Wave Energy Technologies

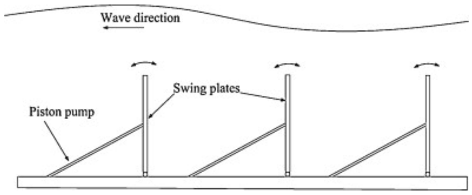
Point Absorber is a buoy that is small compared to the length of the waves, which floats at or near the surface. It can usually absorb energy in all directions by following the movements of water at or near the sea surface (like a float) or, for subsea devices, move up and down under the influence of the variations in subsea pressure as a wave moves by. Energy is generated by transferring these movements against resistance, which can take a number of forms, depending on the configuration of resistance, the power take-off and the type of device-to-shore transmission. Some point absorber generators has a buoyant surface float with an inbuilt PTO that is attached to the sea bed. The movement of the float is converted directly into electricity.



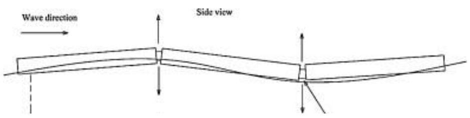
Oscillating Water Column (OWC) comprises a partially submerged structure forming an air chamber, with an underwater aperture. This chamber encloses a volume of air, which is compressed as the incident wave makes the free surface of the water rise inside the chamber. The compressed air can escape through an aperture above the water column which leads to a turbine and generator. As the water inside falls, the air pressure is reduced, and air is drawn back through the turbine. Both conventional and self-rectifying air turbines have been proposed.



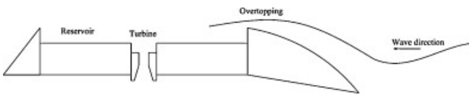
Surge Device extract energy from the horizontal to-and-fro movements of water particles within waves. They are situated in shallower water close to shore, because it is only in shallow water that the circular movement of water particles in deep water then becomes elongated into horizontal ellipses (surge). These devices usually take the form of wide flaps that are pivoted about a rotor. Again, despite the same operating principle, the examples of surge devices deployed vary considerably.



Attenuator/Contouring Devices are elongated floating devices that extend parallel to the wave direction and so effectively 'ride' the waves. As the incoming wave passes along the device, it generates movements within the device that are used to produce energy.



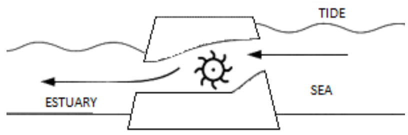
Overtopping Devices rely on using a ramp on the device to elevate part of the incoming waves above their natural height to fill a raised reservoir, from which the seawater can return to the sea via low-head turbines.



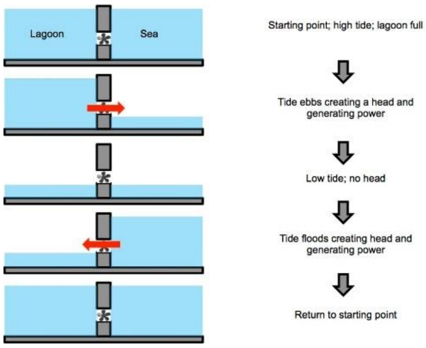
In general, devices working efficiently in milder wave climate such the Baltic will be the preferred solution.

2.2 Tidal and Current Energy Technologies

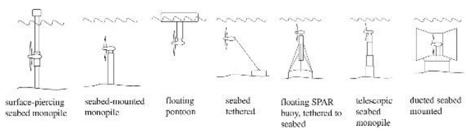
Tidal Barrage is a type of tidal power generation scheme that involves the construction of a low walled dam, known as a “tidal barrage” and hence its name, spanning across the entrance of a tidal inlet, basin or estuary creating a single enclosed tidal reservoir, similar in many respects to a hydroelectric impoundment reservoir.



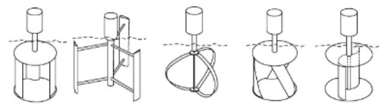
A tidal lagoon is a power station that generates electricity from the natural rise and fall of the tides. As the tide comes in (floods) the water is held back by the turbine wicket gates, which are used to control flow through the turbine and can be completely closed to stop water entering the lagoon. This creates a difference in water level height (head) between the inside of the lagoon and the sea. Once the difference between water levels is optimised, the wicket gates are opened and water rushes into the lagoon through the bulb turbines mounted inside concrete turbine housings in a section of the breakwater wall. As the water turns the turbines, electricity is generated.



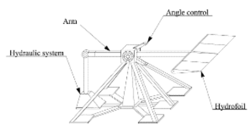
Horizontal axis turbines extract energy from moving water in much the same way as wind turbines extract energy from moving air. The tidal stream causes the rotors to rotate around the horizontal axis and generate power.



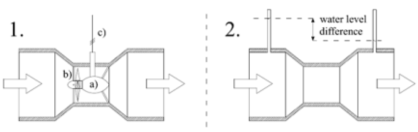
Vertical axis turbines extract energy from the tides in a similar manner to that above, however the turbine is mounted on a vertical axis. The tidal stream causes the rotors to rotate around the vertical axis and generate power.



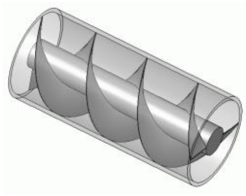
A hydrofoil is attached to an oscillating arm. The tidal current flowing either side of a wing results in lift. This motion then drives fluid in a hydraulic system to be converted into electricity.



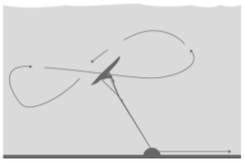
Venturi Effect devices house the device in a duct which concentrates the tidal flow passing through the turbine. The funnel-like collecting device sits submerged in the tidal current. The flow of water can drive a turbine directly or the induced pressure differential in the system can drive an air-turbine.



The Archimedes Screw is a helical corkscrew-shaped device (a helical surface surrounding a central cylindrical shaft). The device draws power from the tidal stream as the water moves up/through the spiral turning the turbines.



A tidal kite is tethered to the sea bed and carries a turbine below the wing. The kite 'flies' in the tidal stream, swooping in a figure-of-eight shape to increase the speed of the water flowing through the turbine.



Many of the tidal devices are or could be applied in river streams as well. As the speed of currents in the Baltic Sea is low, turbines with high efficiency at low streams such as the kite or the Archimedes screw are judged to be most appropriate.

2.3 Ocean energy technologies under research

Despite recent progress, no ocean energy technology developed has so far achieved the level of technological readiness required to be competitive with other RES or enough to ensure commercialisation of the technology (figure 3). Innovation and supply chain involvement are key elements to accelerate the learning curve. Several universities and research institutes work closely with several technology developers across Europe when it comes to materials, power take off, components, subsystems, control systems, condition monitoring systems, operations, anchor systems, electrical architecture etc.

Multiple barriers still limit the development of ocean energy. Plant construction and maintenance costs are still not clear, but can be very high, especially in the start-up phase. Due to a lack of experience, operations at offshore facilities are still carried out by the oil industry and so are costly. In addition, licensing and authorisation costs and procedures are very high and complex: a lack of dedicated or experienced administrative structures results in long permit procedures. Moreover, with the advent of the deployment of ocean energy technologies, coastal management is a critical issue to regulate potential conflicts with other maritime activities over the use of coastal space. The environmental impact of various types of ocean energy devices will not be fully known until large commercial farms are operating. Ocean energy growth has been further slowed by uncertainties over the grid connection of demonstration projects and a lack of collaboration between developers. Despite these challenges, the industrial system is reacting: the supply chain has started to develop bespoke solutions for ocean energy technologies and, for example, in Scotland, Marine Scotland is a one-stop-shop which has made a public commitment to providing responses to consent applications within nine months of submission.

Work is in progress to develop guidelines and standards that enhance project development, evaluation, testing, and comparability. This will better enable stakeholders, such as policymakers, electricity network companies and investors, to select the technologies that meet their needs. Unlike tidal stream technologies, for wave energy technology there is a clear indication that convergence has not yet occurred. However, both persistent R&D efforts and the experience gained over the past years in the fields of new materials, construction, and corrosion have contributed to the ongoing improved performance of ocean energy converters and have brought some devices closer to commercial exploitation than ever before. Different prototypes have proven their applicability in severe operational conditions. Several concepts are at the stage of proving their long-term viability and several commercial plants are currently under consideration. There is a lack of information and understanding regarding performance, lifetime, operation and maintenance of technologies and power plants. For most ocean technologies to succeed, rigorous and extensive testing on prototypes is still necessary to establish the new technologies. Large deployment can be successful with convergence of technologies, thereby reducing the number of isolated actors and allowing technology development to accelerate. Industrial R&D and continuing academic R&D should move in parallel. Research aims to reduce key technological risks. The main challenges facing the industry, according to ETIP Ocean report An Integrated Framework of Ocean Energy Sector Challenges, are:

Category	Challenge
Technology	Developing novel concepts for improved power take-offs (PTOs)
	Increasing device reliability and survivability
	Investigating alternative materials and manufacturing processes for device structures
	Investigating novel devices before moving towards convergence of design
	Defining and enforcing standards for stage progression through scale testing
	Developing and implementing optimisation tools
Financial	Providing warranties and performance guarantees
	Linking stage-gate development processes to funding decisions
	Maintaining grant funding for early TRL technologies
	Establishing long term revenue support
Environmental and socio-economics	Enhancing social impact and acceptance
	Minimising negative environmental impacts
	Facilitating knowledge transfer and collaboration
	Implementing adaptive management systems

2.4 Technologies under demonstration

In 2017, from the available information on 209 ocean energy projects registered (figure 4), 47% belong to wave energy, 49% to tidal, 1% to salinity gradient and 6% to offshore wave and wind. In relation to the status, 16% are operational or installed, 31% are completed or decommissioned, 10% are cancelled, suspended or on hold, and 42% are in planning, consented, in development or under construction, which are almost divided in 50:50 tidal and wave resources. In the case of ocean energy test sites, from the available 30 sites included, 18 of them are operational, 11 are in a previous status (in planning, in development or under construction) and 1 was decommissioned, which are almost divided in 37% tidal and 63% wave (included wave/wind) resources. As seen in figure 4 there is a very high concentration of demonstration projects around UK, Ireland, France due to its natural resources.

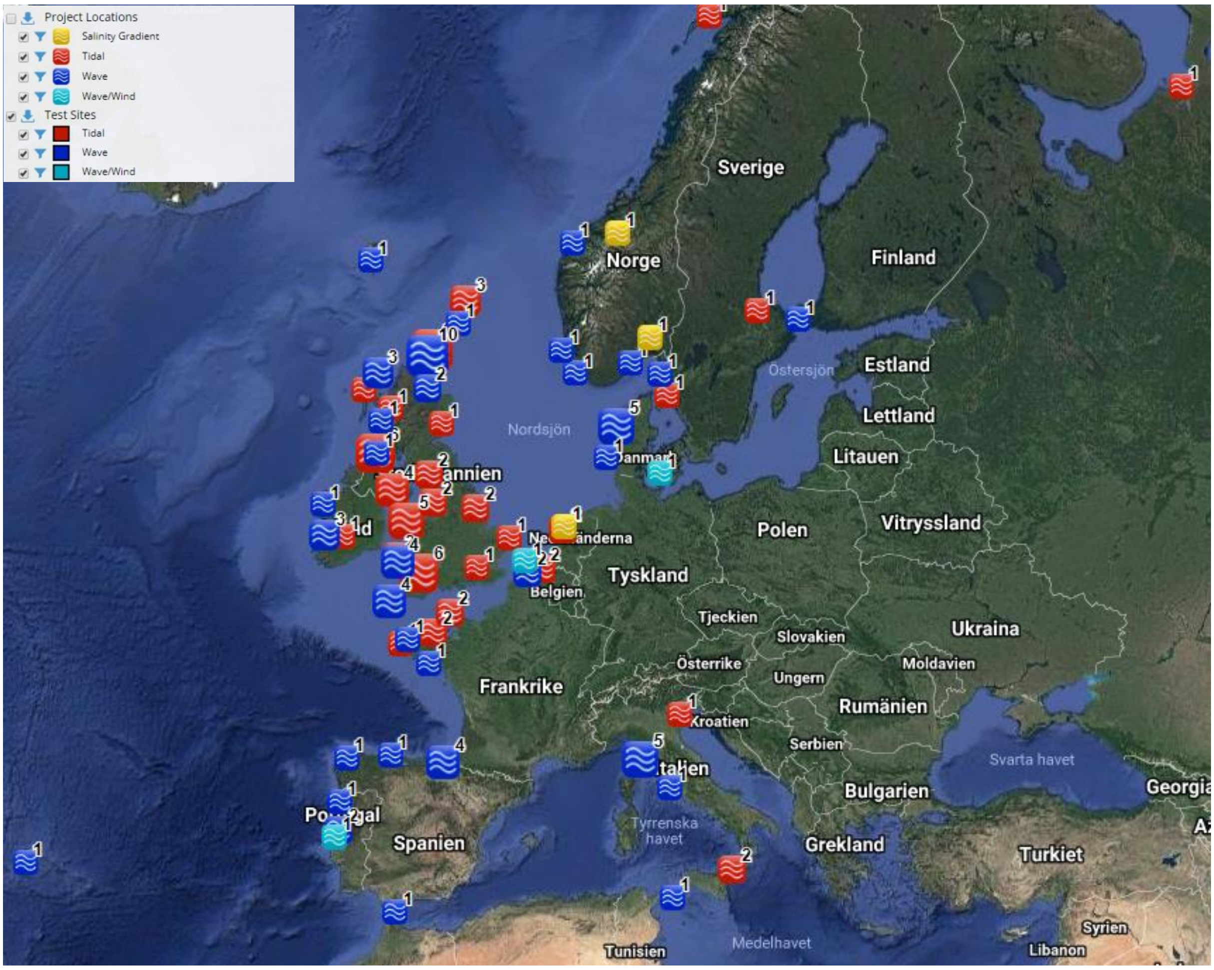


Figure 3 Ocean energy projects in Europe, strong focus around UK, France, Ireland

2.4.1 Tidal (examples)

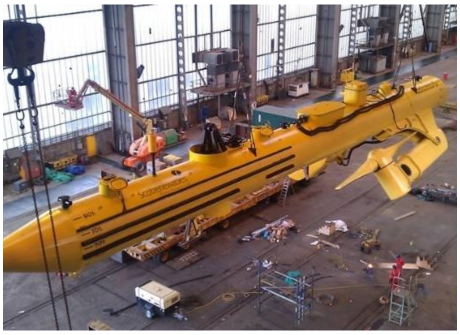


Figure 4 Scotrenewables 1:1 demonstration

Scotrenewables Tidal Power has set another record with its first 2MW floating tidal stream turbine with the unit clocking up over 3GWh of renewable electricity in its first year of testing at the European Marine Energy Centre (EMEC) in Orkney, Scotland, supported via the FORESEA Interreg-NWE funded project. In 12 months of continuous operation, including during the worst winter storms in recent years, the pioneering SR2000 – the world's most powerful operating tidal stream turbine – has supplied the equivalent annual electricity demand of around 830 UK households and at times has been supplying over 25% of the electricity demand of the Orkney Islands. Underlining the significance of the company's achievement, and its contribution to the progress of the tidal industry, the 3GWh generated by the SR2000 over the past 12 months is more power than that generated by the entire wave and tidal energy sectors in Scotland in the twelve years prior to the launch of the SR2000 in 2016. The team at Scotrenewables believes that this, combined with Meygen's generation of over 8GWh over the past year from four tidal turbines deployed in the Pentland Firth, is convincing evidence of tidal power's market readiness.

Atlantis Resources Limited


Figure 5 Atlantis resources demonstration MayGen

They have submitted a strategic plan to the French government that includes a goal to deliver 1 GW of tidal power by 2025 at Le Raz Blanchard in France. The company recently completed a study that concludes 2 GW of tidal energy is immediately available to be harnessed at this site in Normandy and 1 GW could be operational by 2025, with potential to create up to 10,000 jobs and attract more than €3 billion (US$3.65 billion) of CAPEX investment.

Sabella


Figure 6 Sabella 1:2 demonstration

French tidal energy company Sabella has started new set of tests on its D10 tidal energy turbine ahead of its deployment off France planned for August at the earliest. Sabella's D10 turbine has a rotor diameter of 10 meters and is 17 meters tall with the weight of around 400 tons. During its 2015-2016 deployment off Ushant island, the turbine successfully fed clean electricity to the French national power grid.

Minesto


Figure 7 Minesto kite

Developing Holyhead Deep into a tidal energy array will be done in phases. In a first step, one 0.5MW demonstrator, called DG500, will be installed. The purpose of this first installation is to prove functionality and power production performance in utility scale. In April 2017, Minesto was consented Marine License for the DG500 installation in Holyhead Deep. Commissioning of the DG500 device was initiated in June 2018, with initial sea trials taking place in Holyhead harbour and the Holyhead Deep site. The DG500 commissioning program consists of two main phases: First system functionality tests will be performed, before moving on to electricity generation. The first phase of the commission program itself comprises a series of tests over different stages, including verification of launch and recovery procedures, testing of each function of the control system, and finally operating the DG500 unit in full figure-of-eight trajectories. Following successful deployment and testing of the DG500, the ambition is to install further Deep Green devices and gradually expand the site to a commercial demonstration array of up to 10MW installed capacity.

2.4.2 Wave Energy (examples)

OceanTEC


Figure 8 Oceantec 1:1 demonstration

Identification of the WEC concept and starting of the conceptual design was made in 2005. Following the identification of the WEC, in 2006, the International Patent of the OCEANTEC WEC was filed. The Technology was validated through Numerical Simulations and Laboratory Tests in 2007, also the search for investors started the same year after the validation. In 2008 a €4.5m Investment led by IBERDROLA was obtained, and the Technology entirely was transferred to OCEANTEC ENERGÍAS MARINAS, SL. Sea trials of a quarter scale prototype was carried out in the same year as well. Finally, the design of linear absorber or attenuator based on a gyroscopic device for energy extraction was abandoned in favor of an OWC (Oscillating Water Column) with a point absorber. It is typically known as SPAR BUOY OWC. Floating devices for harvesting energy from waves require at least two interacting bodies, so that energy is extracted from its relative movement. In most concepts, it is necessary to guide the movement of one body along another, requiring the existence of bearings and guidance systems which imply large loads in a hostile environment such as the sea. The goodness of the OWC systems is that one of the bodies consists of water, which besides being economical in the sea, it is guided without any concentrated forces. The size of the OWC is 42 m length and 5 m diameter

Laminaria

The final LAMWEC tank tests, prior to deployment at the European Marine Energy Centre, have been completed, building on tank tests conducted in 2016. A 1/30 scale model of Laminaria's 200kW WEC, which is being designed as part of the OCEANERA-NET LAMWEC project, was put through its paces and demonstrated survivability in extreme sea states. Production of the full-scale Laminaria WEC is now underway and is due to be completed by April in preparation for deployment at EMEC's Billia Croo wave test site later in 2018.

Figure 9 Laminaria small scale demonstration

Wello

The Penguin vessel floats on water and captures the kinetic energy of the waves, turning it into electrical power. The vessel is positioned away from the wave breaking zone. The Penguin fleet can consist of anything form one unit upwards, depending on the desired energy production capacity. The Penguins are anchored to sea bottom at a depth of approximately 50 meters. Only 2 meters of each unit is visible above the surface. Instead of fixed structures on the sea bed, the Penguin floats on the surface with only minimal anchoring. The Penguins do not produce any audible or visible disturbance to the nearest shore.

Figure 10 Well 1:2 demonstration

Waveroller

The WaveRoller is a device that converts ocean wave energy to electricity. The machine operates in near-shore areas (approximately 0.3-2 km from the shore) at depths of between 8 and 20 meters. Depending on tidal conditions it is mostly or fully submerged and anchored to the seabed. A single WaveRoller unit (one panel and PTO combination) is rated at between 350kW and 1000kW, with a capacity factor of 25-50% depending on wave conditions at the project site. The technology can be deployed as single units or in farms.

Figure 11 Waveroller 1:1 demonstration

Wave Dragon

The site for the proposed Wave Dragon Pre-Commercial Demonstrator is approximately 1.7km (0.9 nautical miles) off the Pembrokeshire Coast at Long Point. The Wave Dragon Pre-Commercial Demonstrator is a floating slack moored wave energy converter with a rated capacity of 7MW. It is moored (like a ship) in relatively deep water, i.e. more than 25 m to take advantage of the ocean waves before they lose energy as they reach the coastal area. This contrasts with many known wave energy converters that are either built into the shoreline or fixed on the seabed in shallow water.

Figure 12 Wave Dragon 1:1 demonstration

Wavepiston

The concept has been tested in the wave tank of the University of Aalborg. Tests in irregular waves at 4 different wave states. A 1:9 scale model was operated successfully for 7 months at Nissum Bredning in 2013. The figure below shows the 50 m string with 8 ECs before deployment from the beach at Nissum Bredning. The 1:2 scale prototype is a 120-m string with 8 energy collectors attached to the string. Its located 2Nm from the port of Hanstholm.

Figure 13 Wavepiston prototype

Corpower Ocean

After 18 months of testing and final verification of survival and power generation in Scotland, CorPower has proven that its technology has the underlying physics and technical capabilities to produce electricity at a competitive cost. The Swedish Energy Agency has co-financed the current demonstration project in Scotland and, due to the proven good results, has decided to invest another €8.2M to commercialize the technology at full scale.

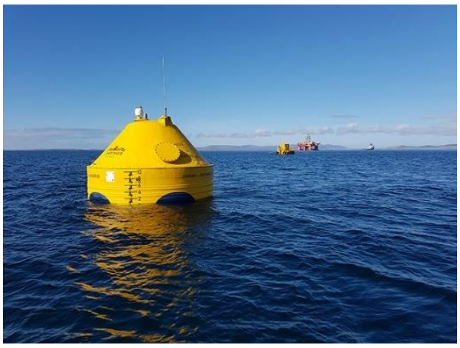


Figure 14 Corpower 1:2 device deployed in Scotland

2.5 Environmental Impact

Most studies have concluded that the environmental impact of wave energy schemes is likely to be low, provided developers show sensitivity when selecting sites for deployment and that all the key stakeholders are consulted (WEC 2007). Marine growth, including sea weed, barnacles and other invertebrates, is expected to occur, especially on the buoy. There is also strong reason to believe that array installations of submerged wave energy converters will create "safe havens" for marine life, as they become artificial reefs with a closed off surface area. The occupied seabed area from the foundations (if gravity-based foundations are used) will inevitably become unavailable for bottom dwelling organisms. The introduction of a new body is expected to create a new habitat in favour of the hard substrate organisms. Wave power parks will hinder commercial fishing, especially with trawls and nets. From the nature conservation perspective these no-take zones can have positive effects on fish populations. It may enhance fish populations, fish size and species richness. The foundations of wave power devices can function as so-called secondary artificial reefs, locally enhancing biomass for several sessile and motile organisms. Wave energy devises may induce both physical and biological changes on habitats. Physical changes that might occur are alterations in currents and waves. This may alter sediment size distribution and that way favour the accumulation of organic material. Biological changes might be alterations in biodiversity and species abundance. On the other hand, introduction of new substrates may also introduce new species which might influence the existing ones. Underwater noise is known not only to affect seals, dolphins and whales, but also several species of fish. Many species use underwater sounds for interaction, like communication, finding prey and mates and avoiding predators. Another topic that is likely to reoccur in wave power projects is electromagnetism. Some marine animals like migratory fish use the Earth’s magnetic field for navigation. Sea cables have electromagnetic fields, but it is still unknown do they have effect on marine species. These both matters need to be studied more. It has been shown that floating structures on the water surface attract both juvenile and adult fish. There is no clear explanation for that, but there are several hypotheses; protection from predators, availability of food, spawning substrates and resting areas. It can be expected that buoy in test site act as fish aggregation device.

When it comes to tidal streams, the flow into and out of the Baltic is essential for the ecological balance of the whole ecosystem. As indicated in the chapter on physical and chemical properties of the Baltic Sea, the areas with the highest currents are present where the critical in water exchange takes place. Regardless the technique used, the water flow will be haltered here, and water exchange limited. Small scale production in river estuaries is often seen as a feasible solution with respect to environmental concerns.

2.6 Adaptation of (commercial) technologies for Baltic Sea requirements

There are no technologies that has been commercialized up to date. There have been numerous test and demonstration projects in the oceans around UK, Ireland, Spain, Portugal etc (see previous chapter). These are designed for seas with waves with higher density of energy. Before an adaptation may occur for more sheltered waters like the Baltic Sea these devices needs to become commercial and market ready, both in terms of reliability and cost. The ocean energy sector predicts that the first ocean arrays will be fully operational in 2030 and it will take between 60 to 100 GW (based on a 3% acceleration of the learning curve) of installations until the cost is competitive with another RES.

Under the optimistic scenario, about 3.9 GW of cumulative installed capacity are expected globally until 2030, given the current level of political support. Of these, 86.7% will be deployed in Europe, and will be tidal stream, tidal range and wave (61%, 26% and 10% respectively). OTEC will contribute to a very minor extent. The tidal stream energy capacity expected in 2030 is just under 2.4 GW, with 93% deployed in Europe. The tidal range energy capacity expected in 2030 is just over 1 GW, all of which operational, with 72% deployed in Europe. In this period, only 2 projects are expected to be deployed in the optimistic scenario, to 320 MW in 2025 and 160 MW in 2030, both in Europe. The wave energy capacity expected in 2030 is just under 0.5 GW, with 87.5% deployed in Europe. Considering the operational capacity, around 380 MW are expected to be online in 2030.

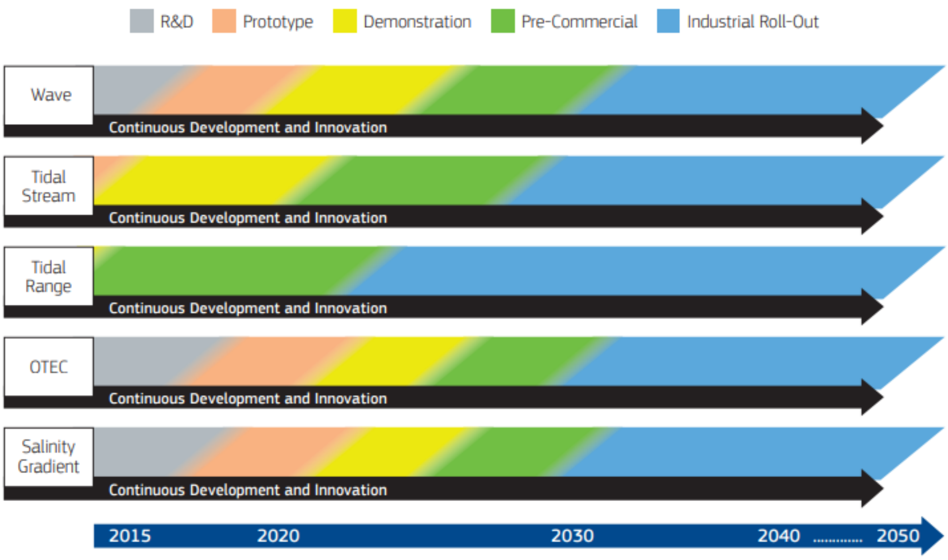


Figure 15 Status of each ocean energy technology

Through interviews with developers they have little interest of deploying in the Baltic sea until they have proven their technology in other places where the resources are more challenging. Once the technologies have been proven they can move to the next stage and adapt their technologies for other types of resources and regional requirements. Until 2050 they see no need for any areas to be reserved for ocean energy arrays. The only reason for ocean energy to take place in the work with spatial planning is the need for research and testing of component and small-scale prototypes.

3 Marine Biofuel technologies

Many potential pathways exist for the conversion from algal biomass to fuels. These pathways can be classified into the following three general categories:

1 Those that focus on the direct algal production of recoverable fuel molecules (e.g., ethanol, hydrogen, methane, and alkanes) from algae without the need for extraction;
2 Those that process whole algal biomass to yield fuel molecules; and Those that process algal extracts (e.g., lipids, carbohydrates) to yield fuel molecules.

2.1 Macro Algea

Macroalgae have recently attracted attention as a possible feedstock for energy. Macroalgae have high productivity, which is high as or higher than terrestrial plants, and macroalgae do not compete with crops for arable land. Macroalgal biomass provides environmentally and economically feasible alternatives to fossil fuels. The Baltic Sea is under great environmental stress and suffers from environmental problems such as eutrophication. Macroalgae have a great potential eutrophication effect through nutrient removal processes, even if an excess of algae growing could create a lack of oxygen within the biota with an impact on the biodiversity dimension. Thus, a macroalgae-based industrial system would be beneficial for the overall nutrient level in the Baltic Sea and become a favourable and sustainable feedstock for energy purposes. Intensive cultivation of macroalgae is likely to increase with the development of an algal biofuels industry and algal bioremediation. However, target macroalgae species suitable for cultivation in the Baltic sea have not yet been identified.

2.2 Micro Algea

Microalgae refer to small size algae which shape can only be seen under the microscope. Microalgae are the main primary producers in the aquatic ecosystem (Becker, 2004). Chlorella, spirulina and Nitzschia as the main microalgae sources are usually used to produce biofuel (Chisti, 2007). They are sort of single primitive cell organism with high photosynthesis capability. The growth period is short, and the cell doubling time of microalgae is only 1-4 days. Microalgae which contain at least 30% lipids in the microalgae cell have possible to be used to convent biofuel.

2.3 Algal Biofuel Conversion Technologies

Potentially viable fuels that can be produced from algae range from gaseous compounds like hydrogen and methane, to alcohols and conventional liquid hydrocarbons, to pyrolysis oil and coke. Attractive targets for this effort, however, are the liquid transportation fuels of gasoline, diesel, and jet fuel. These fuel classes were selected as the best-value targets because 1) they are the primary products that are currently created from imported crude oil for the bulk of the transportation sector, 2) they have the potential to be more compatible than other biomass-based fuels with the existing fuel-distribution infrastructure and 3) adequate specifications for these fuels already exist.

The direct production of biofuel through heterotrophic fermentation and growth from algal biomass has certain advantages in terms of process cost because it can eliminate several process steps (e.g., oil extraction) and their associated costs in the overall fuel production process. There are several biofuels that can be produced directly from algae, including alcohols, alkanes, and hydrogen.

Alcohols – Algae, such as Chlorella vulgaris and Chlamydomonas perigranulata, can produce ethanol and other alcohols through heterotrophic fermentation of starch (Hon-Nami, 2006; Hirayama et al., 1998). This can be accomplished through the production and storage of starch via photosynthesis within the algae, or by feeding sugar to the algae directly, and subsequent anaerobic fermentation of these carbon sources to produce ethanol under dark conditions. If these alcohols can be extracted directly from the algal culture media, the process may be drastically less capital- and energy-intensive than competitive algal biofuel processes. The process would essentially eliminate the need to separate the biomass from water and extract and process the oils. This technology is estimated to yield 15,000 - 23,000 litre per acre per year, with potential increases up to 38,000 litre per acre per year within the next 3 to 4 years with significant R&D. It is theoretically estimated that one ton of CO^2 is converted into approximately 225 – 250 litre of ethanol with this technology.

Alkanes – In addition to alcohols, alkanes may be produced directly by heterotrophic metabolic pathways using algae. Rather than growing algae in ponds or enclosed in plastic tubes that utilize sunlight and photosynthesis, algae can be grown inside closed reactors without sunlight. Instead of getting energy for growth from sunlight, the algae get concentrated energy from the sugars fed into the process. These higher cell concentrations reduce the amount of infrastructure needed to grow the algae and enable more efficient dewatering if is required.

Hydrogen – The production of hydrogen derived from algae has received significant attention over several decades. Biological production of hydrogen (i.e., biohydrogen) technologies provide a wide range of approaches to generate hydrogen, including direct biophotolysis, indirect biophotolysis, photo-fermentation, and dark-fermentation. The future of biological hydrogen production depends not only on research advances, i.e., improvement in efficiency through genetically engineered algae and/or the development of advanced photobioreactors, but also on economic considerations, social acceptance, and the development of a robust hydrogen infrastructure.

In addition to the direct production of biofuels from algae, **the whole algae can be processed** into fuels instead of first extracting oils and post-processing. These methods benefit from reduced costs associated with the extraction process, and the added benefit of being amenable to processing a diverse range of algae, though at least some level of dewatering is still required.

Pyrolysis – Pyrolysis is the chemical decomposition of a condensed substance by heating. Pyrolysis has one major advantage over other conversion methods, in that it is extremely fast, with reaction times of the order of seconds to minutes. Unfortunately, there are also significant gaps in the information available about the specifications for converting algal bio-oil and the resulting products. The optimal residence time and temperature to produce different algal bio-oils from different feedstocks need to be carefully studied. Work also needs to be performed to understand the detailed molecular composition of the resulting bio-oils. Additionally, research is needed on the catalytic conversion of the resulting algal bio-oils. Another area of interest is the development of stabilizers for the viscosity of the bio-oil and acid neutralizing agents, so the bio-oil may be more easily transported throughout the upgrading process.

Gasification – Gasification of the algal biomass may provide an extremely flexible way to produce different liquid fuels, primarily through Fischer-Tropsch Synthesis (FTS) or mixed alcohol synthesis of the resulting syngas. The synthesis of mixed alcohols using gasification of lignocellulose is relatively mature and it is reasonable to expect that once water content is adjusted for, the gasification of algae to these biofuels would be comparatively straightforward. FTS is also a relatively mature technology where the syngas components are cleaned and upgraded to usable liquid fuels through a water-gas shift and CO hydrogenation.

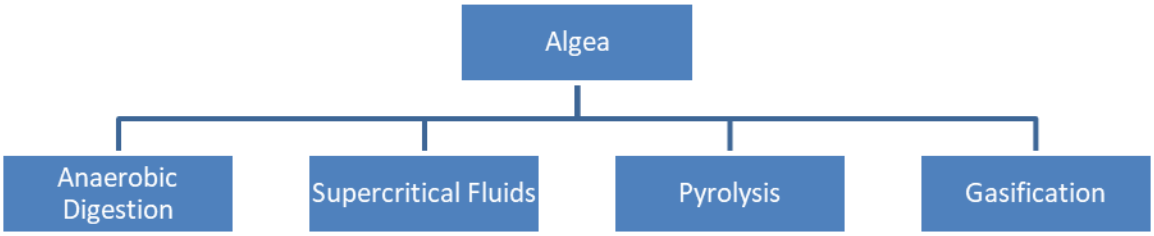


Figure 16 Schematic of the potential conversion routes for whole algae into biofuels

2.4 Marine Biofuel research

This is an often-overlooked aspect and worth highlighting. Technology transfer, the availability of research facilities and training programs are the key to successful alga aquaculture. There is considerable know-how in the countries around the Baltic Sea in this regard and the aquaculture programs are vital to development of the industry.

We face some significant technical hurdles before biofuels production from algae will be possible at a significant commercial scale. To overcome these challenges, we are working to answer some basic questions such as:

- Why do algae utilize a relatively small amount of available light energy?
- What tools can be used to improve light utilization efficiency of algae and to improve production characteristics?
- How do you develop an organism that will produce significantly more bio oil?

The central challenge is that algae naturally harvest significantly more light than they can effectively convert to biofuels. Only a fixed amount of light hits the surface of a pond, and our goal is for the algae to use this light as efficiently as possible. The amount of wasted sunlight varies greatly depending on the algae species and growth conditions but can be as high as 80 percent or more. The challenge is to find and develop algae that can produce bio-oils at scale on a cost-efficient basis.

It would require a significant amount of algae to produce enough fuel to satisfy even a small portion of global road transportation fuel demand. Population and economies will continue to expand along with energy demand and CO2 emissions. An integrated set of solutions will be required to increase efficiency, expand supply and mitigate emissions. Technology breakthroughs will be critical and algae-based biofuels could contribute to this set of solutions. The ultimate goal is to have algae bio-oils processed in refineries to supplement supplies of conventional gasoline, diesel, aviation fuels, and marine fuels. Global demand for transportation-related energy is projected to increase by about 25 percent through 2040 and accelerating the reduction in emissions from the transportation sector will play a critical role in reducing global greenhouse gas emissions. Predictions on success are difficult and depend directly on the pace of technological innovation. It could potentially take decades or more for advanced biofuels to reach a scale that would significantly benefit the transportation fuels sector.

3 Analysis of EU and national policies

Member states need to come together to support common initiatives and build common practices and policies that support the development of technologies that will help to reduce greenhouse gas emissions.

3.1 Ocean Energy

The EU is currently at the forefront of ocean energy technology development, and currently hosts more than 50% of tidal energy and about 45% of wave energy developers. To date, the majority of ocean energy infrastructure such as ocean energy test centres and deployment sites are also located in European waters.

3.1.1 European Support

The Energy Union Strategy, launched in early 2015 and being one of the 10 big priorities of the European Commission (EC), includes research, innovation and competitiveness at the same level of importance with its 4 other dimensions, for accelerating the decarbonisation of the European energy system cost-effectively. The Strategic Energy Technology (SET) Plan has been recognised as one of the major tools to deliver this goal by contributing to the cost reduction and improve of performance of low carbon energy technologies through impactful synergetic innovation actions. As part of the deliverables of the Energy Union strategy, the European Commission adopted a Communication for an Integrated Strategic Energy Technology Plan. The Communication identifies ten priority actions to accelerate the energy system transformation through coordinated or joint investments between European countries, private stakeholders (including research and industry) and the European Commission. These actions have been defined building on the proposals of the Integrated Roadmap (that was developed with stakeholders and Member States) and in line with the new political priorities defined in the Energy Union strategy. The first round of the public consultation process was dedicated to the 1st Energy Union Research, Innovation and Competitiveness common priority, for "being the world leader in developing the next generation of renewable energy technologies including environment friendly production and use of biomass and biofuels, together with energy storage". It focused on Actions 1 and 2 of the SET Plan Communication (C(2015)6317) and out of the ten priorities, these actions are the most relevant action for the Ocean Energy:

- To sustain technological leadership by developing highly performant renewable technologies and their integration in the EU's energy system
- To reduce the cost of key technologies

An EU Strategy for the Baltic Sea region was approved by European Council in October 2009. The Strategy aims to make this area more environmentally sustainable, prosperous, attractive and safe and secure. The countries around the Baltic Sea are joining forces to save their shared inland sea and to strengthen the competitiveness of the region. The Strategy focuses on fifteen priority areas. At least one of the partner countries acts as a leader for each priority area. Using wave energy in Baltic Sea can promote several of these priority areas of the Strategy.

Mechanisms at European level are in place to support the development of technology from early stage prototypes through commercialisation. European, National, Regional and Ocean-ERA-NET programmes have contributed to fund ocean energy projects for a total of 1.36 b EUR, of which 776 m publicly funded. Projects expected to begin in 2018 and 2019 such as NER300 and demonstration projects are accounted in the analysis. A breakdown of the funds and project cost is provided in Table 1. presents the breakdown of funds given to wave and tidal energy technologies. In total, 270 m EUR of funds have been directed to Wave energy R&D, and 470 m EUR to tidal energy. In contrast, in the period between 2008 and 2017, the United States Department of Energy has provided $327 million in funds to ocean energy, of which 77% directed to wave energy R&D. Collaboration initiatives at regional level are catalysing the formation of marine energy clusters to consolidate the European supply chain. Meeting the ambitious targets of the SET-Plan require intensified collaboration between the different players to sustain the policy drive for the development of ocean energy in Europe.

Table 1 Breakdown of funds for ocean energy through European National, Regional and OceanERANET

Programs	Total Projects Cost (€)	Funding Contribution (€)
OceanERA-NET	11,984,284	8,000,000
ERDF	264,941,103	209,509,646
EU	657,529,725	363,731,270
National	436,629,384	199,288,780
Total	**1,364,908,496**	**76,382,084**

As of year-end 2017, 9 of the 25 OES member countries had specific ocean energy targets on their national action plans. Action plans or roadmaps are intended to set out an agreed vision for the ocean energy sector. These plans usually outline the actions required by both private and public sectors to facilitate the development and deployment of ocean energy technology. Some of these roadmaps are technology focused providing a guide for mobilising national efforts down a deployment pathway towards a target.

Market deployment policies

As of year-end 2017, several countries have introduced “Market push” mechanism to incentive the development of the first commercial ocean energy projects. 7 countries (UK, The Netherlands, Denmark, France, Italy, Canada and Japan) have adopted feed-in policies (FIT) making this the most widely adopted regulatory mechanism to promote ocean energy in the OES member countries. In UK, the support scheme for wave and tidal energy is based on “Contracts for Difference (CfD)” auctions introduced in 2014 replacing the Renewable Obligations system in the UK. Tradable green certificates are used in four countries (Belgium, Norway, Sweden and Korea). In Korea, the Tradable Renewable Energy Certificates (REC) supplement the Renewable Portfolio Standards (RPS) policy. The United States relies particularly on tax incentives to support renewables like the Business Energy Investment Tax Credit (ITC) in general.

Table 2 Mapping of current Ocean Energy activities in MS and Regions and indicative available support

	Is there a national Ocean Energy Policy outlined?	Is there an assigned Ministry/ Department owner at Government Level?	Is there operational responsbilility for the delivery of the Ocean Energy porgrammes	National PRIORITY ACTIONS - TECHNICAL	PRIORITY ACTIONS - ENVIRON	PRIORITY ACTIONS - FINANCE	PRIORITY ACTIONS - OTHER	2016 - Amount (€M) spent on Ocean Energy by MS	2017 budget planned	Estimated Budget allocation from 2018-2020 (note this is not considered as commitment only an indicative estimate of possible allocation of budget to 2020)
IE	YES	YES	YES	YES	YES	YES	YES	4M EUR	5M EUR	Yes - Under the OREDP the Government committed 30M EUR up to 2020
BE	NO*	YES	NO				YES	0.6M EUR		
CY		YES	NO	YES	YES	YES	YES	99M EUR	20M EUR	
DE										
ES	NO *	YES	YES	YES			YES	1M EUR	TBC	
ES (Basque)	YES	YES	YES	YES		YES		2.5M EUR	2.5M EUR	Demonstration programme: 5M EUR
ES (Cantabria Region)		YES	YES	YES			YES	6.0M EUR		
FR	YES	YES	YES							
FR (Normandy)	YES	YES	YES	YES			YES			
PT	YES	YES	YES	YES	YES	YES	YES	0.44M EUR	18.9M EUR	23.15M EUR
IT	YES	YES	YES	YES	YES	YES	YES	1M EUR	0,5M EUR	Yes - approximately 6M EUR up to 2020 through competitive national projects
SE	No *	YES	YES	YES	YES	YES	YES	4.3M EUR	2.7M EUR	3.9M EUR allocated so far (from Swedish Energy Agency). NB: most likely more funding will be allocated
UK (NI)	YES	YES	YES	YES	YES	YES	YES	No	No	N/A
UK(Wales)	YES	YES	YES	YES	YES	YES	YES	3M EUR	8M EUR	45M EUR
UK (Scotland)	YES	YES	YES	YES	YES	YES	YES	15 M EUR	15 M EUR	45M EUR
UK (BEIS)										

Other policies

There are other policies being implemented by OES member countries. There is a consensus that it is necessary to streamline and accelerate the consenting processes by removing excessive administrative and cost burdens. Regulatory and administrative policies and frameworks, such as consenting, environmental impact and planning procedures, can simplify the process of deploying technology by clearly instructing developers on how to secure consent for a project. Some policies have been implemented to reduce administrative barriers such as: i) One-stop-shop approach, e.g. one responsible authorisation agency acting as a single point of contact for dealing with consents. Ii) Marine Spatial Planning (MSP) in order to coordinate decisions on the uses of marine resources, iii) Guidance and advice on consenting of ocean energy device deployments and iv) Ocean testing facilities at different scales, providing grid infrastructure and equipment to measure the resource.

3.1.2 National Support

Finland, Denmark and Sweden include ocean energy in their national strategies and actively supports research and innovation through public funding.

NATIONAL STRATEGY SWEDEN

Ocean energy is included in both the national maritime strategy and the regional strategy for Västra Götaland. This has resulted both in research programs from the Swedish energy agency and cluster initiatives (Maritime Cluster and OffshoreVäst) to support the sector. In 2016, the Government together with several other political parties agreed on a long term bipartisan energy policy for Sweden. The agreement includes a target of 100 percent renewable electricity production by 2040 and no net emissions of greenhouse gases in the atmosphere by 2045. Additionally, in 2015, the Ministry of Enterprises, Energy and Communications enacted a national maritime strategy which identifies areas where action is needed to promote a sustainable development in the Swedish maritime sector. Ocean energy is one of many areas included, and there is on-going work to identify indicators for each area to track progress and its impact on the vision of the maritime strategy.

The long-term Swedish energy policy relies on economic policy instruments, including a carbon tax, international emissions trading and a renewable electricity certificate system. All these instruments provide incentives for renewable energy and do not specifically target a particular renewable electricity conversion technology, i.e. are technology neutral. There are no instruments in place to specifically incentivise ocean energy deployment.

Swedish governmental agencies support academic and private sector R&D at various stages of technology maturity. Funding providers include:

- The Swedish Energy Agency, www.energimyndigheten.se, is responsible for facilitating a sustainable energy system in Sweden. As such, the agency funds research, business and technology development and technology demonstration relevant to the sustainability of the energy system and the energy industry sectors.
- The Swedish Research Council, www.vr.se, which, among other things, is tasked to fund fundamental research and expensive equipment for research purposes within a large number of topic areas.
- The Swedish Governmental Agency for Innovation Systems (VINNOVA), www.vinnova.se, supports business and technology development.
- In addition, regional authorities may also grant funding.

In 2018, the Swedish Energy Agency initiated a national ocean energy programme with the aim to strengthen research and development capabilities and increase the cooperation between and within academia and industry. The programme will run for four years and has a total budget of around €11 million. A total of 16 projects have been provided with funding from the last programme with support for €5 million. The Swedish Energy Agency is also involved in OCEANERA-NET and OCEANERA-NET Cofund, which are collaborations between national/regional funding organisations, and EU to support the ocean energy sector and fund transnational projects.

<u>National strategy Denmark</u>

Mission: Turn Denmark into a leading laboratory for testing of new maritime technologies, digital systems, production and operating modes, as well as energy production.

The institutional landscape for energy technology R&D in Denmark is complex. Organisations responsible for setting priorities include the Ministry of Climate, Energy and Building, and the Ministry for Science, Innovation and Higher Education. Other ministries contributing include the Ministry of Transport and the Ministry of the Environment. Agencies and intermediary bodies include the Danish Energy Agency, the Danish Agency for Science, Technology and Innovation, the Danish Environmental Protection Agency, the

Danish Board of Technology, the Board of Danish Research Councils (and six Danish Research Councils), the Fund for Advanced Technology (an independent government board) and the grid operator Energinet.dk.

The six Research Councils are the Danish Council for Independent Research; the Danish National Research Foundation; the Danish Council for Strategic Research; the Advanced Technology Foundation; and the Danish Council for Technology and Innovation.

The government supports research, development and demonstration (RD&D) directly by funding institutions and programmes. To a great extent, public funding is prioritised on the basis of strategies devised jointly between industry, research communities and authorities. A relatively large amount is spent on demonstrating and supporting the market penetration of newly developed energy technologies.

EDDP funds the development of new climate-friendly energy technologies. The aim is to promote energy efficiency and help make Denmark independent of fossil energy by 2050. Projects supported by EDDP must also aim to develop Danish commercial potential, so as to promote growth and employment. EDDP has a basic budget of €50.3 million a year solely for supporting Danish companies that focus on new energy technologies and their introduction to the global market.

The Danish Council for Strategic Research supports research into sustainable energy and the environment. In 2013 the Council is more specifically supports activities within the following themes: Energy Technologies and Energy Systems of the Future (€36.2 million); and Environmental Technology (€4 million).

New wave energy technologies can be demonstrated at two of Denmark's open-sea wave energy test sites. The DanWEC test site is suitable for testing of prototype devices, while Nissum Bredning sheltered test site is well suited for trials of scaled devices. Wave energy is estimated to be able to contribute 15% to the total Danish electricity consumption and create opportunities for export of components, products and jobs, according to Ocean Energy Systems.

National strategy Finland

The Government of Finland has approved the investment aid scheme for renewable energy and new energy technologies as part of the country's ongoing efforts to achieve national and EU climate goals. The Government allocated a total of €80 million for the investment aid in 2017 and 2018, for investments of more than €5 million related to pilot projects for new energy technology and production of advanced transport biofuels. The Government of Finland plans to increase the use of renewable energy in a sustainable way to more than 50% during the 2020s, and self-sufficiency to more than 55%. The Government programme also envisages that the share of renewable transport fuels will be raised to 40% by 2030 and that Finland will stop using coal in energy production and halve the use of imported oil for domestic needs during the 2020s.

3.2 Policy support for marine bioenergy

The European government has planned to mandate to source 10% transport energy from renewable resources, primarily from biofuels by 2020. A significant share of the fuels goes into transportation application in the region owing to high demand for luxury vehicles, commercial trucks, and motorcycles.

4 Potential of different technologies in the Baltic Sea, Kattegat in Skagerrak

To stimulate the adaptation of technology and increase the possibilities for ocean energy array deployments the sector would need policy developments to stimulate ocean energy developments. These include renewable energy polices at global levels (Paris agreement), European level (EU energy policy and national targets, which will increase demand for space for offshore energy production.

Industrial developments including:

- New designs and optimization that are specific for these resources, to enable increased turbine capacity, reduce project costs and at the same time decrease environmental impact
- New technologies, technological innovation on energy storage and distribution will contribute to the deployment of new farms and increase the potential of ocean energy.

4.1 Ocean energy projects

4.1.1 Wave

In the Baltic region only, single unit devices have been deployed and tested in jointed research by universities:

- The WESA (Wave Energy for a Sustainable Archipelago) project was a joint research effort between the Åland Innovation Cluster, the University of Turku and Uppsala University. In 2011, Seabased supplied the generator to a pioneering wave energy conversion project in the waters outside of Åland Islands of Finland. Project WESA introduced full-scale sea trials of a Seabased WEC in all four seasons in the Baltic Sea. Experiments were conducted with two buoys, including an ice buoy (Seabased, 2018). It was concluded that the WEC and buoy system could handle ice-interaction of the kind encountered at the temporary test site during two winter seasons. The system survived drifting ice fields up to a maximum ice thickness of 15 cm according to satellite radar (SAR) of the area.

- The university of Klaipéda in Lituania has tested a small-scale device for a short amount of time within the SUBMARINER project. The system was tested in open sea conditions and technical parameters recorded. As there were no possibilities to leave the device for a longer period, proper characteristics was not possible to collect. But technical solution was proved to be working. Prototype testing showed that the generator, despite its relatively small dimensions and low cost materials, operates efficiently and produces substantial amount of electric power.

In Kattegat there have been prototype testing from Danish developers.

- Crestwind will start to test a prototype just outside Fredrikshavn during 2018/2019. (Marineenergy.biz, 2018)
- Floating Power Plant is combined wind and wave energy device. The P80 prototype is a floating platform that hosts a single wind turbine ranging from 5 MW to 8 MW. Between 2008 and 2013 Floating Power Plant successfully completed four grid connected tests on a half-scale prototype at Vindeby offshore wind turbine park, Denmark.

In Skagerrak

- Seabased and Uppsala university has been testing its generators in ocean environments since March of 2006. The trials have been carried out across all 4 seasons, and generator run times have varied from 1 - 15 months. More than a dozen Seabased generator tests and 2 marine substations have been tested at Islandsberg, including our first open sea test of a WEC in 2006 and the first serial test of 3 generators in 2009.
- The Sotenäs project was a joint effort between Seabased, Fortum, and the Swedish Energy Agency.The Swedish Energy Agency awarded an investment grant to Fortum and Seabased for the wave power plant in February 2010.

4.1.2 Tidal and Currents

There are currently no tidal energy projects in the Baltic. (4cOffshore, 2018). In Norway there are 8 different projects listed of which three are decommissioned, 4 have consent authorized and one is dormant. There is no information publicly available on planned projects in the Baltic Sea, while quite some rivers draining into the Baltic have current turbines installed.

4.1.3 Bio masses

Only minor projects could be identified at the Swedish West Coast. There is quite a potential in the Baltic for projects connected to energy based on ocean-based bio masses.

4.1.4 Thermal

No projects could be identified. There is no information publicly available on planned projects.

4.1.5 Salinity

No projects could be identified. There is no information publicly available on planned projects.

4.2 Ocean Energy

The potential of ocean energy arrays in the Baltic sea before is 2050 is rather small. No developer has declared any interest to install ocean energy arrays. There have been a few tests on how to handle ice scenarios and functionality on small scale, but those tests have been more in the interest of universities rather then originate from a need of the developers.

4.2.1 Areal requirements of ocean energy technologies (arrays and test sites)

Corpower Ocean has compared their future arrays with offshore wind and they estimate that an array of approximately 300 units is equivalent to an offshore wind array with 9 units (4km^2). There are currently no plans to establish any ocean energy arrays in the Baltic Sea to convert energy in large scale. The technology that has been or is under current development has until today performed very small-scale testing without any needs for allocated areas. The first deployments will take place in the waters around UK, Ireland, Spain, Portugal, France for both large scale demonstrations and ocean energy arrays. However, the need for component and subsystems development will still be of interest for these technologies. Test and demonstration places for RI&D activities are important.

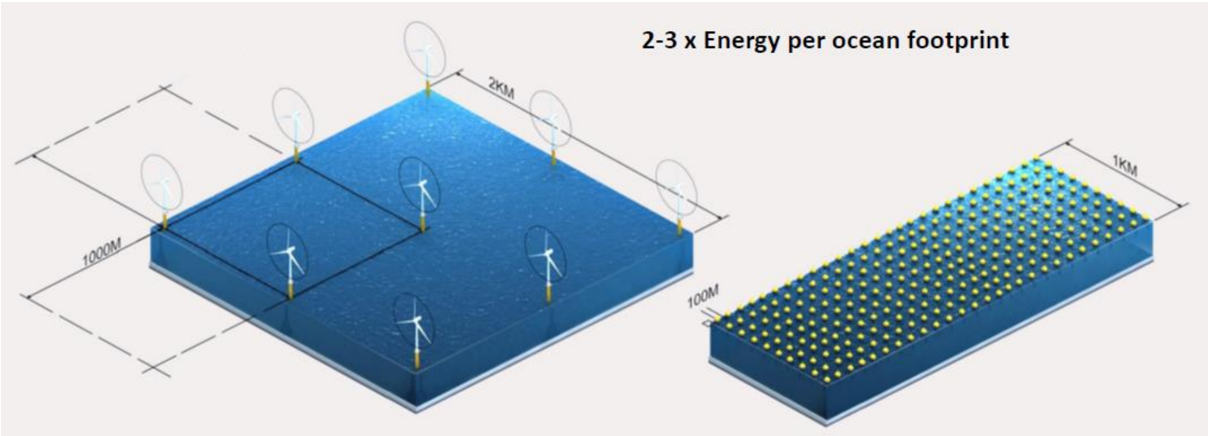


Figure 17 Estimated area for ocean energy array in comparison with offshore wind (Corpower Ocean)

4.2.2 Placing of technologies (arrays and test sites)

The Baltic sea

The theoretical wave power resource of the Baltic Sea (excluding areas where the wave power flux is lower than 5 kW/m and potentially ice-covered regions) is estimated to be 1 GW. Interestingly, the resource is confined to the southeaster region of the Baltic Sea (figure 16). It is estimated that the average wave power flux in the whole Baltic Sea can reach 4–5 kW/m, whereas at the near-shore area along the Lithuanian coast, the multi-year average wave power potential reaches 1–2 kW/m. In discussion with technology developers they point to the waters outside Klaipėda, Latvia as potential for future deployments.

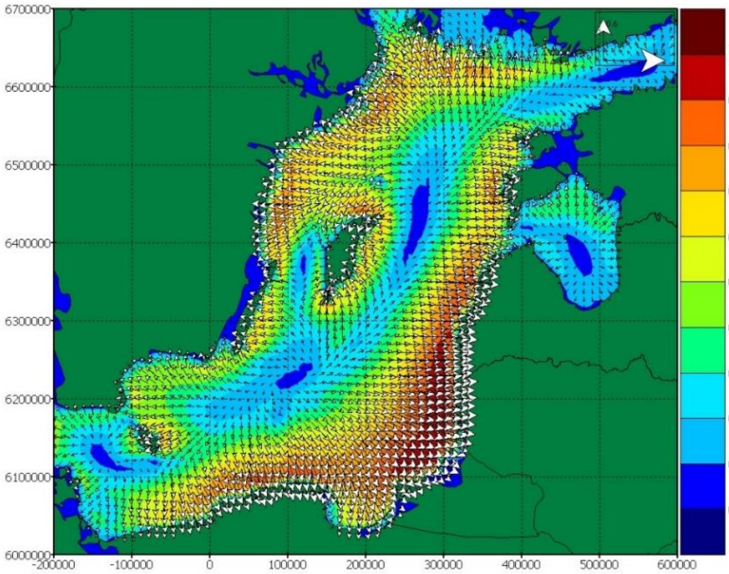


Figure 18 Average direction of wave energy transport in the Baltic Sea

Adaptation of future commercial technologies requires RI&D areas that are relevant for the different techniques for both near shore and offshore testing. Åland and Estland have identified resources that would promote early stage testing. These sites need to accommodate 1-3 units to cover small devices but also small-scale arrays. The size of these areas is estimated to 0,2-0,4 km^2, depending on the layout of the devices. These sites can be compared to the test site at Islandsberg 0,5 km^2 on the West coast of Sweden.

Kategatt and Skagerrak

Kategatt is mainly for short term testing of ocean energy devices and not for future deployments due to restriction on resources (wave energy density), spatial planning (shipping lanes etc) and environmental concerns.

Skagerrak is suitable for future deployments of arrays and will more likely be subjected to deployments then Kategatt and the Baltic Sea. The waters outside the municipality of Lysekil and Sotenäs are the obvious one's due good mapping of the resources and long-term prototype testing in the area.

Dedicated Test Sites

The Islandsberg marine research site has been up and running since 2004 with over 10 wave power plants, marine substations and grid connection installed between 2005 and today. The test facility has expanded during the years until today with a total area of 0.5 square kilometers at 25 meters depth and is located 200 km north of the Gothenburg area. The wave climate at the site is relatively calm by international standards, approximately 3 kW/m annual average, wave heights reaching a maximum Hs of approximately 4.5m. The site is well situated for smaller scale tests and has good accessibility.

The Sotenäs Test Site is located in Skagerrak in the, North Sea, Swedish waters outside the municipality of Sotenäs and the town Smögen, 120 km N of Gothenburg. The area is approximately 0.8 square kilometres with a dept of 50-70 meters. This is a test and demonstration site for Seabased Inc. since 2010.

The future of the test site is today uncertain, Seabased and Fortum has decommissioned the site and discussion is progress to investigate future scenarios.

Both sites are dedicated test and demonstration sites for technology development and not for long term energy production. (Seabased, 2018). In 2018 Energistyrelsen, Denmark gave permit to Crestwing for test and demonstration of their technology, to be placed at Hirsholmene, Frederikshavn. (Danish Energy Agency, 2018).

Some testing has been performed in Latvia and there is one area dedicated to wave energy that has a substantial space for installation (27km^2), based on GIS information received within the project.

4.3 Marine Biofuel

The potential of marine biofuel farms in the Baltic sea, Skagerrak and Kattegat is rather small before 2050 due to technical hurdle that needs to overcome.

4.3.1 Areal requirements of marine biofuel technologies

There are at least three separate sources to consider. These include the exploitation of **natural seaweed stocks**, the use of **drift seaweed**, and the **cultivation of seaweed** at either coastal sites or using offshore infrastructure such as that used for wind farms, ocean energy systems or another aquaculture.

In other countries with significant exploitation of natural stocks such as Norway and France, it is considered that a natural kelp bed must be allowed at least 5 years to regenerate after harvest, so a figure of 20% harvest of natural stocks would be a reasonable upper limit to sustainable annual harvest.

1) Suitability of a site with respect to requirements of the target seaweed species
2) Feasibility of aquaculture development with respect to availability of space and competition with other interest groups and coastal resource users (e.gfishermen, shipping, yachting, tourism, protected areas)

The total liquid fuel demand is high, many believe algal biofuel will never be able to meet the demand.

For example: In US 2016, the demand for liquid fuels was approximately 19.6 million barrels per day. Data collected from the Kona demonstration center shows that the productivity of algae is about 0.5 barrels/hectare per day. From these numbers, it is possible to calculate the approximate land area needed to grow enough algae to meet the United States' liquid fuel demand: 400 000 square km of land, or about 4 percent of the total U.S. land area (equivalent to about half the size of Texas). To put this in perspective, about 17 percent of U.S. land is currently being used to grow crops. Moreover, vehicle electrification and better fuel efficiency can help substantially reduce the need for liquid fuels, reducing the impact of biofuel production.

Nearshore Seeweed Aquaculture – Several criteria have to be met for selection of an aquaculture site with respect to logistical operation of a farm. These criteria include exposure of a site, pier access, access to the hinterland and other activities in the potential area. In the study some potential seaweed aquaculture sites are listed and generally described according to certain selection criteria. Some examples are given interpreting the selection parameters and implications, which can be drawn from them. Only major bays, loughs etc. are considered. The coast in the Baltic sea, Skagerrak and Kategatt have many suitable areas that provides:

- A large number of sheltered to semi–sheltered sea loughs, bays, inlets and estuaries.
- Good water exchange and different strength of tidal currents.
- Generally unpolluted water.
- Different degrees of nutrient enrichment.
- On average, lower water turbidity than at the east coast due to different bottom substrata.

With respect to the availability of space and competition with other coastal resource users, two major issues are highlighted: the opportunity for a close link of seaweed, shellfish and finfish aquaculture, and the implications of the presence of Special Areas of Conservation and Special Protected Areas.

Offshore Seeweed Aquaculture – Seaweed aquaculture can be considered as a stand-alone activity, building the required infrastructure to cultivate seaweed on a very large scale offshore. Such schemes have been proposed in the US (Chynoweth, 2002) and in Japan (Yokoyama, et al., 2007) as outlined earlier. It is unlikely that a program on such a scale would be undertaken prior to 2030 in the Baltic Sea, without trials being conducted at smaller scales and the very significant engineering challenges posed by offshore seaweed aquaculture solved.

4.4 Physical and chemical properties of the Baltic Sea

The Baltic Sea is an arm of the North Atlantic Ocean, extending northward from the latitude of southern Denmark almost to the Arctic Circle and separating the Scandinavian Peninsula from the rest of continental Europe. The largest expanse of brackish water in the world, the semi-enclosed and relatively shallow Baltic Sea has a rather low water turnover from the North Atlantic and receives mainly fresh water from the river run-offs which results in low salinity especially in the easterly and northern parts. (Encyclopædia Britannica, 2018). The relatively small water volume in the Baltic Sea offers a small degree of dilution, so when a given contaminant load occurs it will result in higher concentration compared to anthropogenic input to other more distinctive marine areas with higher water turnover rates. (Elfwing & Svedäng, 2010).

Other physical and chemical features that characterize the Baltic Sea are (Elfwing & Svedäng, 2010):

- the large, densely populated catchment areas,
- Shallow water compared to the Atlantic Sea and the North Sea,
- Low temperature,
- Ice and snow cover,
- Short day conditions in autumn and winter,
- Permanent stratification of water because of halocline,
- Temporary stratification of water because of thermocline (Furman et al. 1998)
- Minimal tidal sea level fluctuations
- High sedimentation rates compared to oceans (This should be considered together with increased sediment resuspension in shallow areas, see above)

- Hydrodynamic fronts e.g. in the eastern Gulf of Finland
- Brackish water, salinity range from 0 to 20 ppt
- Low calcium concentration compared to oceans

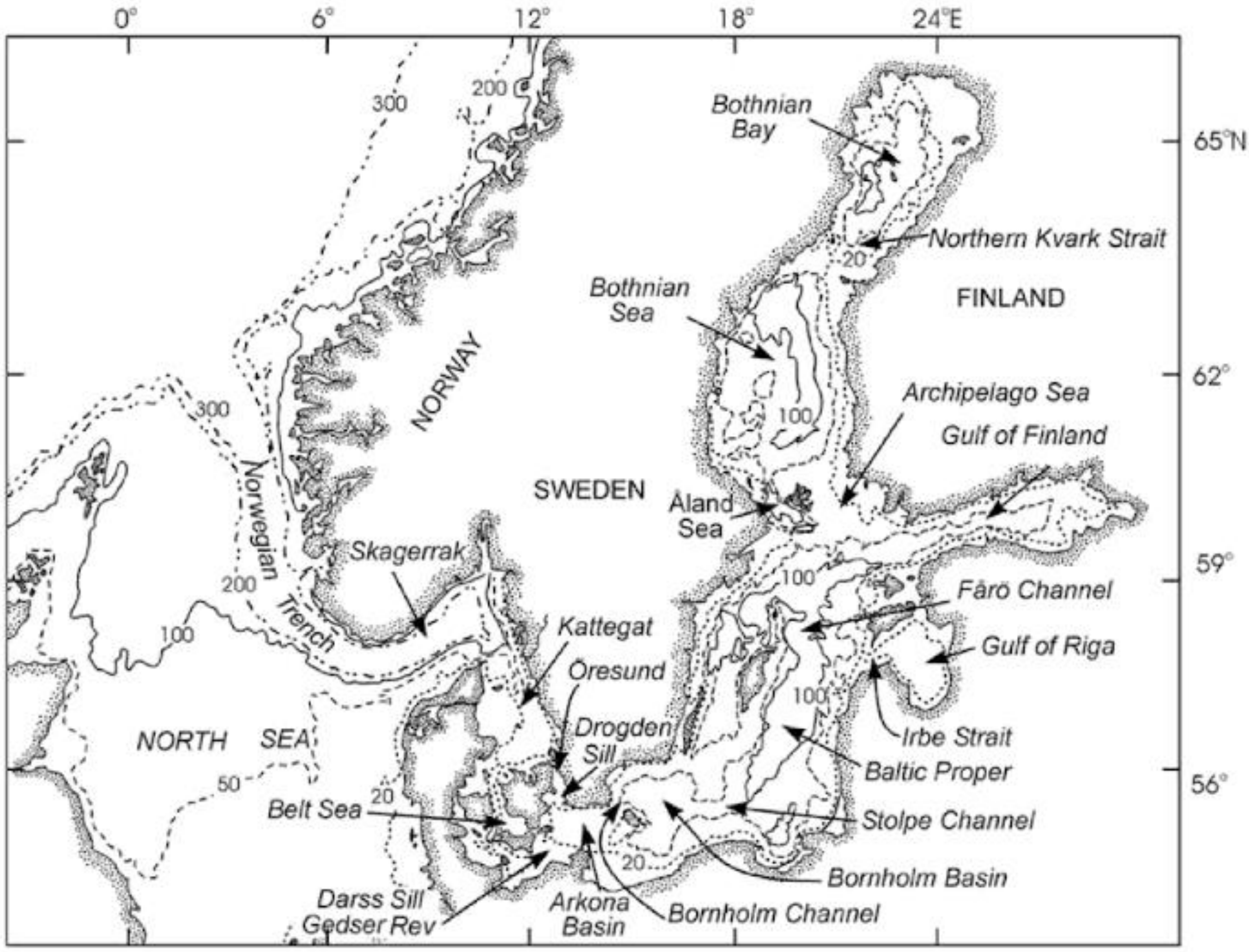


Figure 19: The Baltic Sea-North Sea region with depth contours indicated (Omstedt, 2015)

The total area is 377 000km^2 to 415 000km^2 depending on where the limits are drawn in the Kattegat and Skagerrak and has including the Kattegat a volume of 21 700 km^3. The catchment area is 1 650 000 km^2, more than four times the area of the sea itself. Almost 100 million people live around the Baltic Sea (Encyclopædia Britannica, 2018). It is typically divided into sub-regions that are shown in the figure below. There is a large-scale circulation of water driven by the rivers with freshwater, limited by the narrow entrance areas in the straits of Denmark. On its way to the Kattegat and Skagerrak, the brackish water becomes increasingly saline in the higher layers, while dense bottom water originating from the North Sea flows into the Baltic and fills the deeps, when temperatures, winds and currents allow for this exchange in the shallow straits.

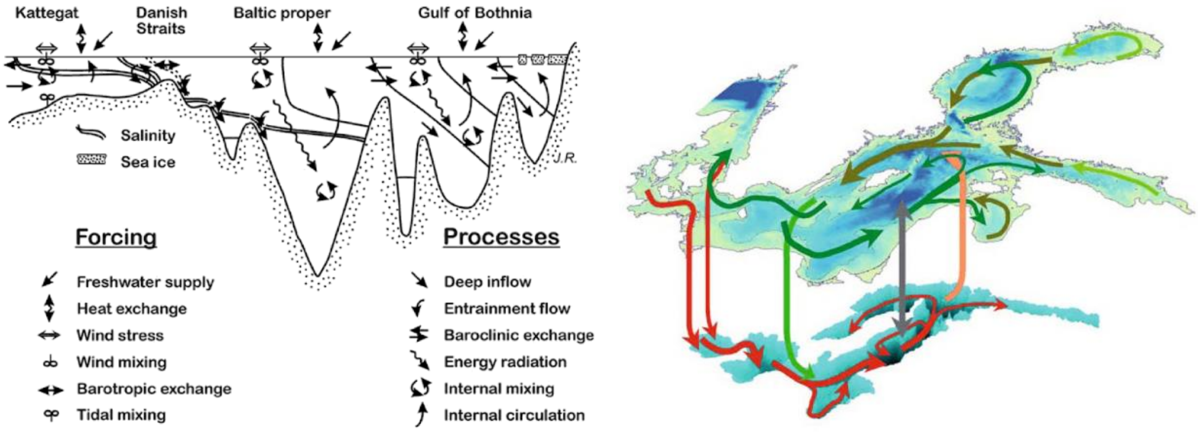


Figure 20: Left: Conceptual model of the Baltic Sea. On the left are processes that force the exchange and mixing and on the right processes that distribute the properties within the Baltic Sea Right: Conceptual model for mean circulation. Deep layer circulation between the halocline is given in the lower part of the figure.

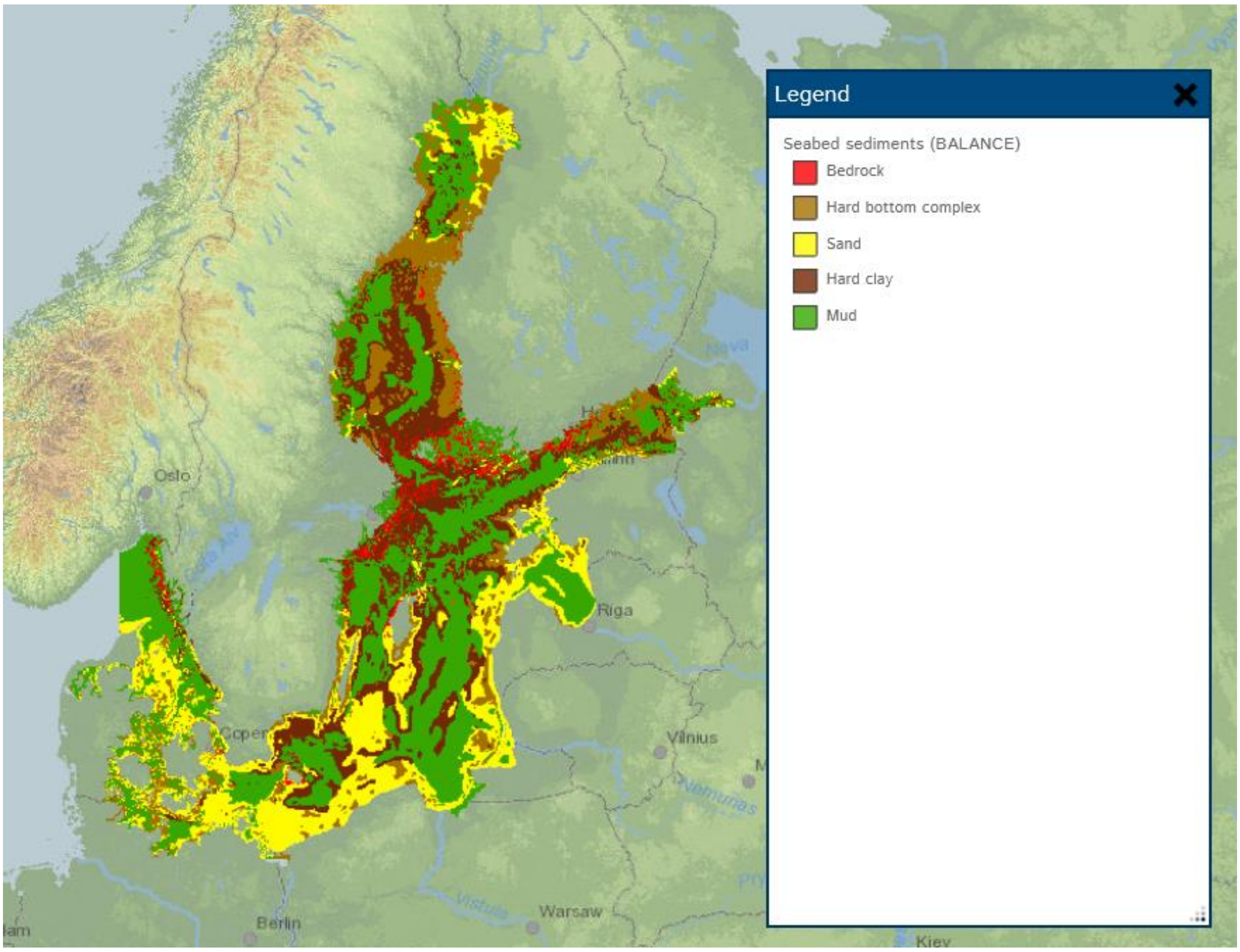


Figure 21: Seabed sediments in the Baltic Sea. Data Source: HELCOM

The bottom types in the Baltic consists of a variety of geophysical properties. Many parts consist of sand and mud, while other parts are dominated by hard bottom complex, hard clay and bedrock. These differences have an impact on bottom fixed and moored structures and the costs connected to appropriate bottom fastening.

The Baltic is a rather young sea, formed after the last glaciation as the ice retreated some 10 000 years ago. Geological uplifting of land after the glaciation continues, especially in the northern part where the uplift causes the coastline to retreat noticeably within a human generation. (Heino, 2013) The water depth in the Baltic is up to about 500m in depth in the Baltic Proper east of the island of Gotland and contains rather shallow parts around the Danish islands and in the Gulf of Finland. Where there are sandy bottoms the water depth is often shallower, while in the deeper parts, mud and hard clay is prevailing. Especially in the Finnish and Swedish archipelagos the bedrock bottom is present together with hard clay or hard bottom complex.

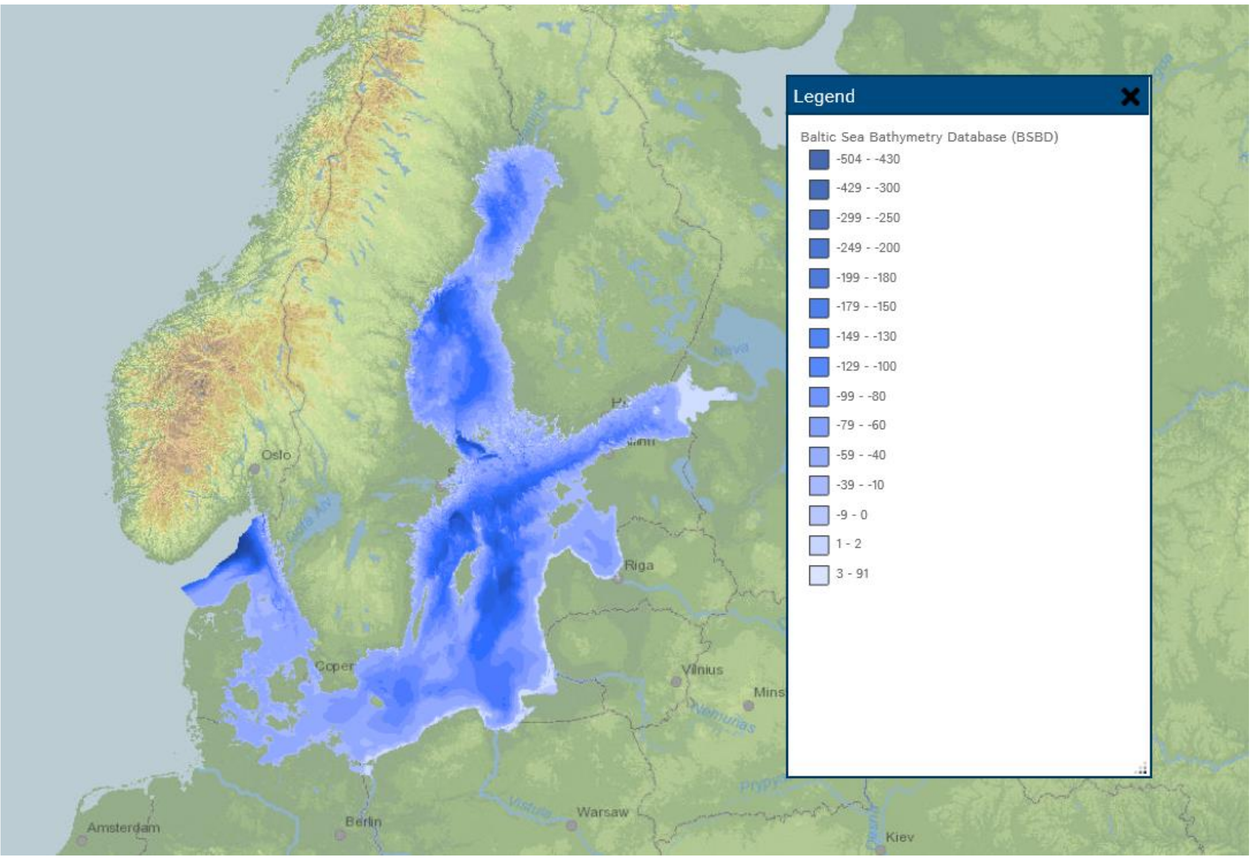


Figure 22: Water depth in the Baltic Sea [m], Data Source: HELCOM

4.5 Energy profiles and resources in the Baltic Sea region

This chapter describes the energy profiles and resources available in the Baltic Sea. The resources can be split into wind, waves, tidal and stream currents, temperature and salinity. There is a dependency between these resources, but they are described separately anyway.

4.5.1 Wind resources in the Baltic Sea region

Wind resources are typically numerically modelled based on satellite images and wind measurements. They have different resolutions in time and space. Important is to know the wind content in the area at various heights, the variability of the wind, seasonality and sensitivity to distance to coastlines and other obstacles. The assessments made in this study are based on coastdat data[1]: *coastDat is a model-based data bank developed mainly for the assessment of long-term changes in data sparse regions. A sequence of numerical models is employed to reconstruct all aspects of marine climate (such as storms, waves, surges etc.) over many decades of years relying only on large-scale information such as large-scale atmospheric conditions. The approach was developed over more than 10 years and has been applied successfully to various issues in the North Sea including, amongst others, assessments of the effectiveness of political measures to reduce chronic oil pollutions or changes in wind and storm surge climate. The Coastdat data set is used by more than 100 users with about 40% of them located in economy, 15% in authorities and 45% in research institutes.*

The wind energy content is than typically calculated based on representative power curves for wind turbines, that describe the energy production for various wind speeds. In this work, the data from the Coastdat projects have been used to calculate the wind power content and the possible

[1] https://www.coastdat.de

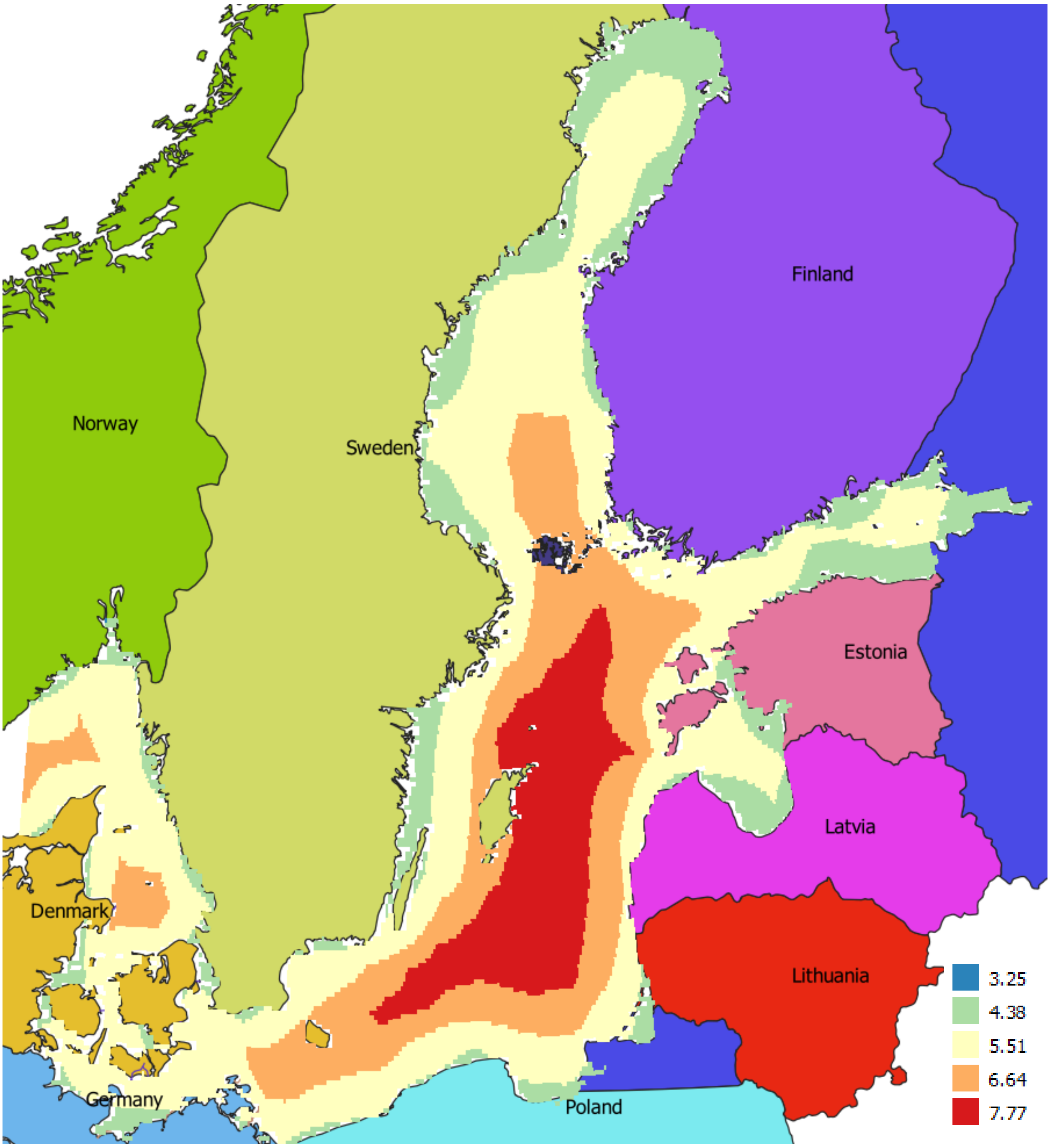


Figure 23: Average wind speeds [m/s, one hour mean] in the Baltic Sea based on numerical simulated data from coastdat

The usable power input is calculated according to the standard methods used for wind atlases.[2]

[2] http://drømstørre.dk/wp-content/wind/miller/windpower%20web/en/tour/wres/powdensi.htm

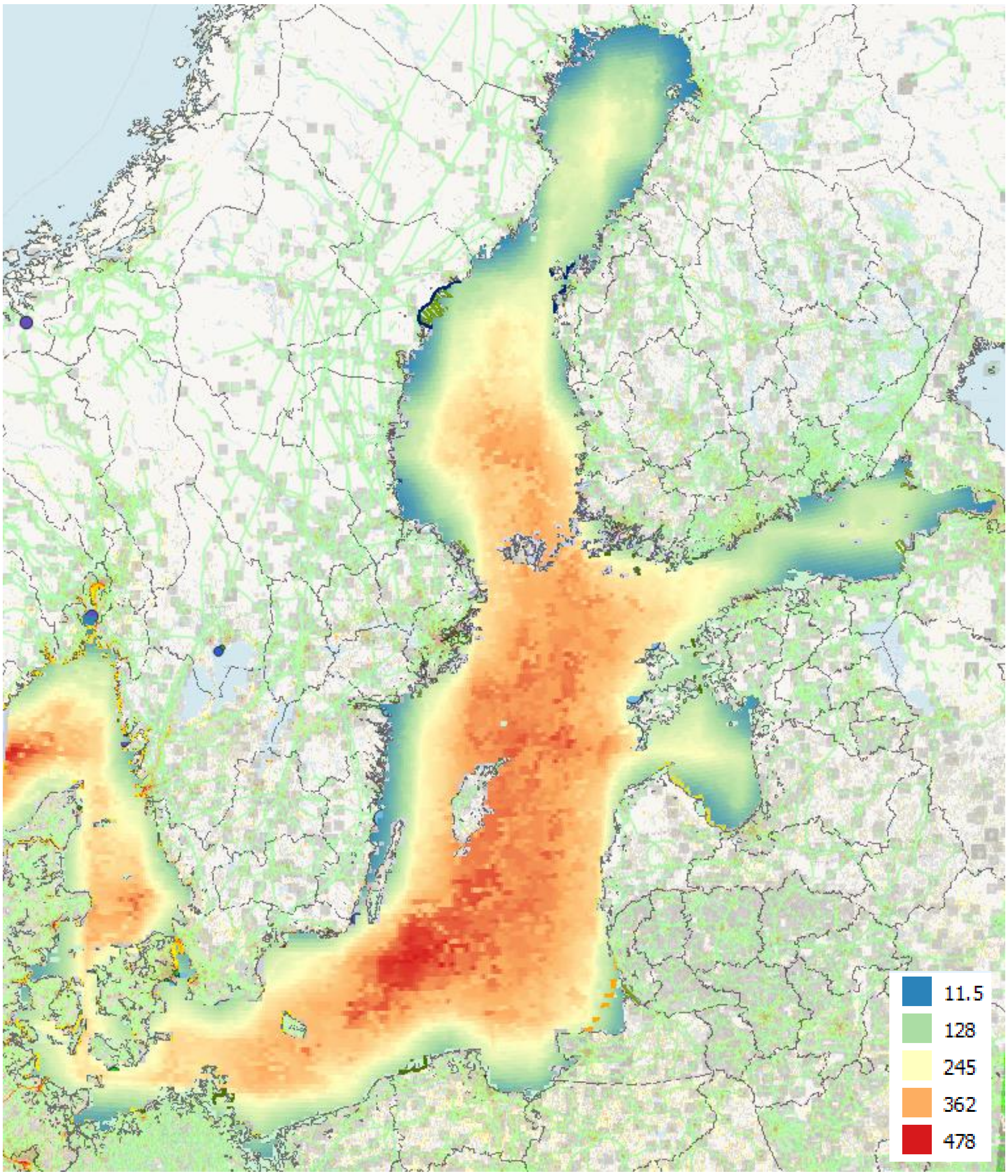


Figure 24: Usable power density of wind speeds in the Baltic Sea based on numerical simulated data from coastdat. Usable power density implies the wind power available based on the wind speed distribution

4.5.2 Wave resources in the Baltic Sea region

Sea waves are mainly created by the wind. The wave heights and periods are steered by the winds, currents, coastlines and bathymetry. Wherever the wind has the chance to fetch water (fetch length), the wave height measured and experienced increases. Due to the shallower water in the Baltic Sea, the waves are steeper than in the North Sea. The effects of the fetch length are visible in the chart below describing the average wave height. As there are predominant westerly and southwesterly winds in Northern Europe, the highest waves heights are often present a bit east off the coastline where enough fetch is present.

To extract wave energy in a cost-efficient way, a certain level of energy content must be present in the water, often measured in kW/m2 sea area.

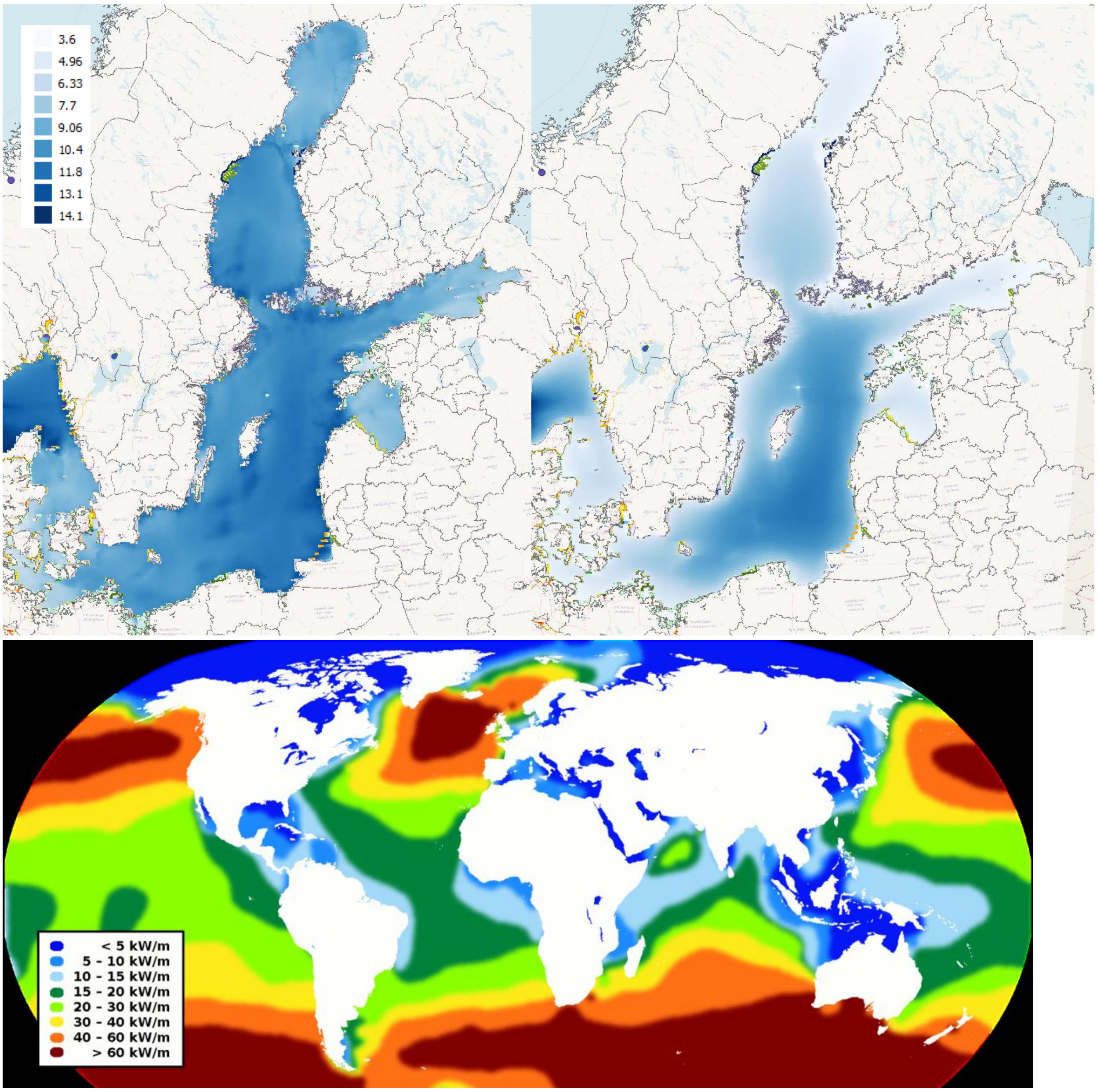


Figure 25: Numerically simulated 1h average significant wave height and wave power energy content [kW/m^2] in the Baltic Sea in 1958-2002 based on coastdat data and Worldwide energy potential (https://en.wikipedia.org/wiki/Wave_power). Compared to the worldwide wave energy potential, the Baltic Sea is probably not the first choice for establishing parks.

4.5.3 Tidal currents and current resources in the Baltic Sea region

Sea currents can be generated by different parameters, among these are the tidal motion, wind stress, density difference in the water column due to differences in salinity or temperature and even seismic activity and motion of the earth. Especially tidal currents are often extracted close to the sea bottom. To extract the energy from tidal waters, a certain current level must be present. Due to the limited exchange of water in-between the different basins of the Baltic Sea, the obstruction by tidal turbines can affect the limited flow further. Therefore, the best places for tidal turbines are potentially affecting the water quality and lead to environmental concerns. The bottom currents in the Baltic are illustrated below based on HELCOM data. The highest currents are present in the Kattegat and Skagerrak for the whole area.

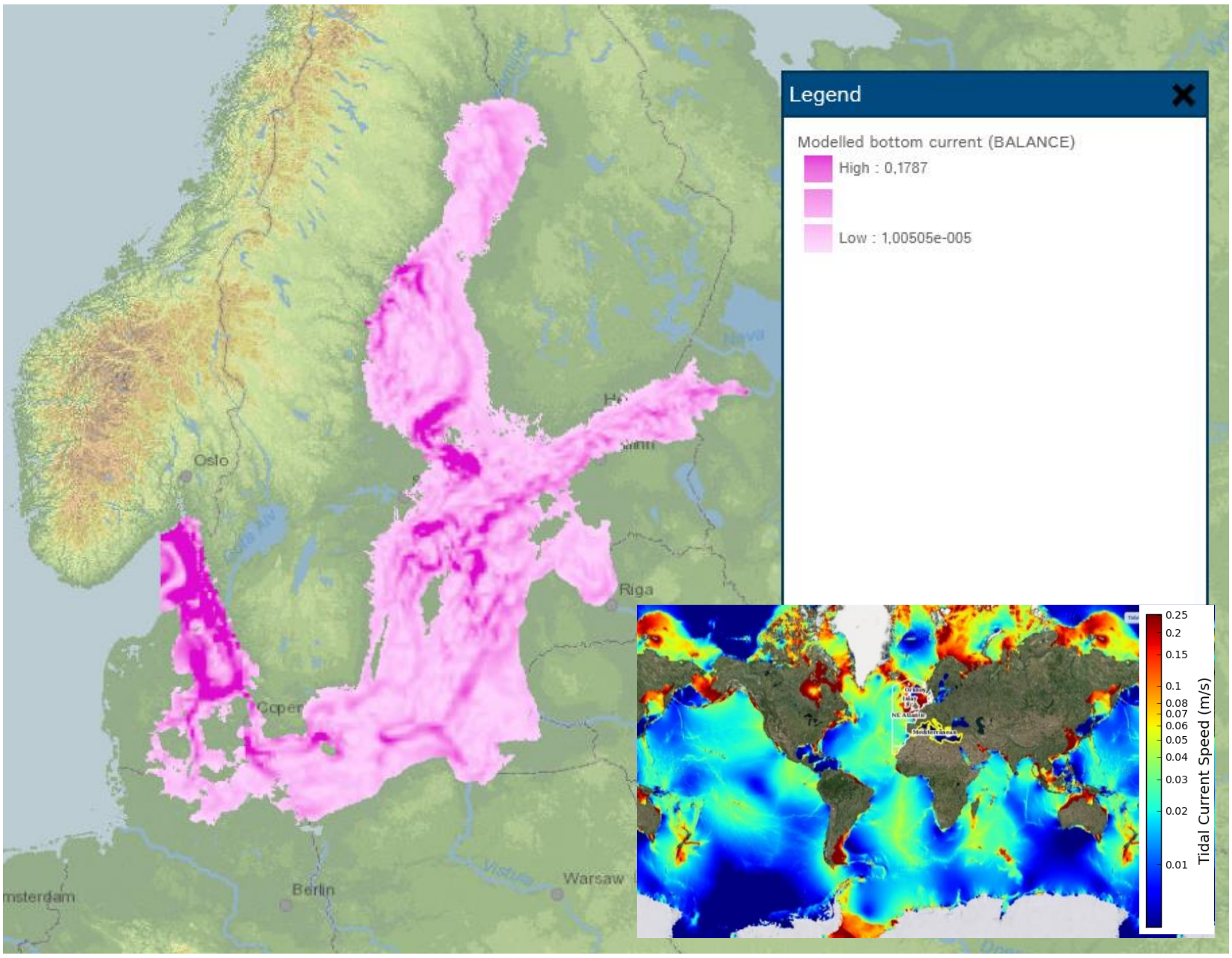


Figure 26: Annual averaged modelled bottom currents [m/s] in the Baltic Sea region based on data from the Balance project, Data Source: HELCOM and global (m/s) tidal speed, http://tips.noveltis.com/. Compared to the worldwide tidal energy potential, the Baltic Sea is probably not the first choice for establishing parks.

The tidal forces don't have the same order of magnitude in the Baltic Sea compared to larger ocean. Tide cause only few centimeters up to decimeters of water level variation at most of the coastal areas. Instead the most important factors influencing water level in the Baltic are the

- atmospheric pressure: High atmospheric pressures push the water surfaces downwards. A density gradient of one mill bar corresponds to one centimeter of water level change, so normal changes in atmospheric pressures can thus shift the water levels tens of centimeters
- wind and wind variations, even on local scale: Wind piles up water to certain areas of the Baltic, especially inner bays where the highest amplitudes of water level changes can be found.
- In near shore regions, the wave-induced currents along the shores are often the dominating currents, whereas in more offshore regions, a combination of the tidal and the meteorological forces are the dominating current generating parameters. (HELCOM, 2018)

- the currents through the Danish straits: Water flows in and mainly out of the Danish straits and changes the total volume of Baltic water and thus to the water level in many parts of the Baltic. Currents are often caused by water level differences between the Atlantic and the Baltic and strong winds in the area.

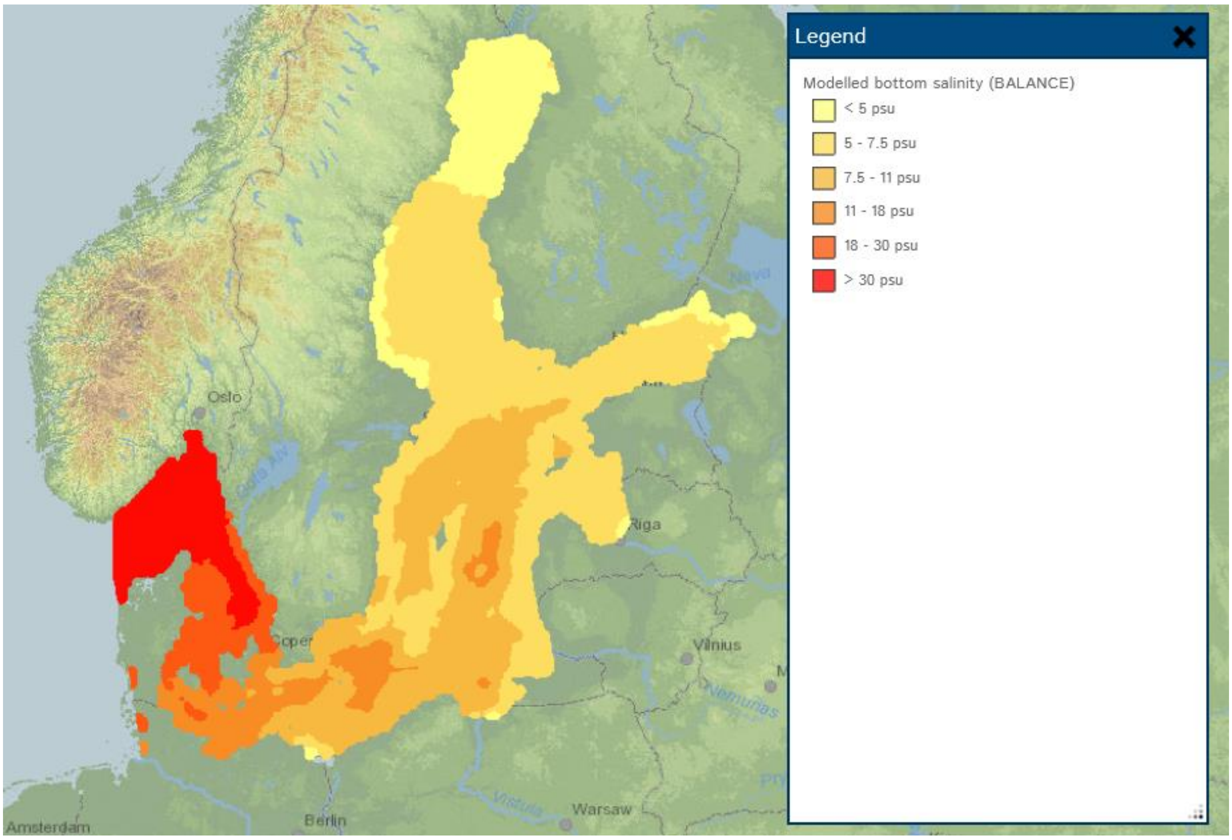


Figure 27: Average modelled bottom salinity [psu] in the Baltic Sea region based on data from the Balance project, Data Source: HELCOM

- during winter, the extent of ice cover and its effects (Heino, 2013)
- Closer to the sea bottom, the friction of the current flow forms a turbulent layer, termed boundary layer, over the seabed. The thickness of this layer depends on the current strength and bathymetry and can therefore range from few meters up to several tens of meters. The variation of the current speed with height within this layer describes the current speed increase that is nonlinearly with the height above the seabed. It is zero at the seabed and maximum at the top of the layer; in this water column, the direction can change with height as well. (HELCOM, 2018)

4.5.4 Salinity resources in the Baltic Sea region

The level of salinity in the Baltic Sea is limited that could be used for osmotic power production. Salinity at the water surface is the direct result of the relationship between the components of the water balance, while salinity and oxygenation of water in deep parts of the Baltic depend on the frequency and volume of salt water infusions from the North Sea. The inflow of salty water into the main Baltic Sea is limited and has a huge variation from year to year based on the prevailing currents, winds and temperatures. The salinity is the highest in the deeper parts of the Baltic Proper and in the Kattegat. For salinity projects a certain level of salt gradient is needed to produce energy.

4.5.5 Temperature/ Thermal resources in the Baltic Sea region

Sea temperature is an indicator for ice coverage in the Baltic Sea and as a resource for energy production. Annual mean temperature in the air decreases gradually from south and west to north and east. The sea

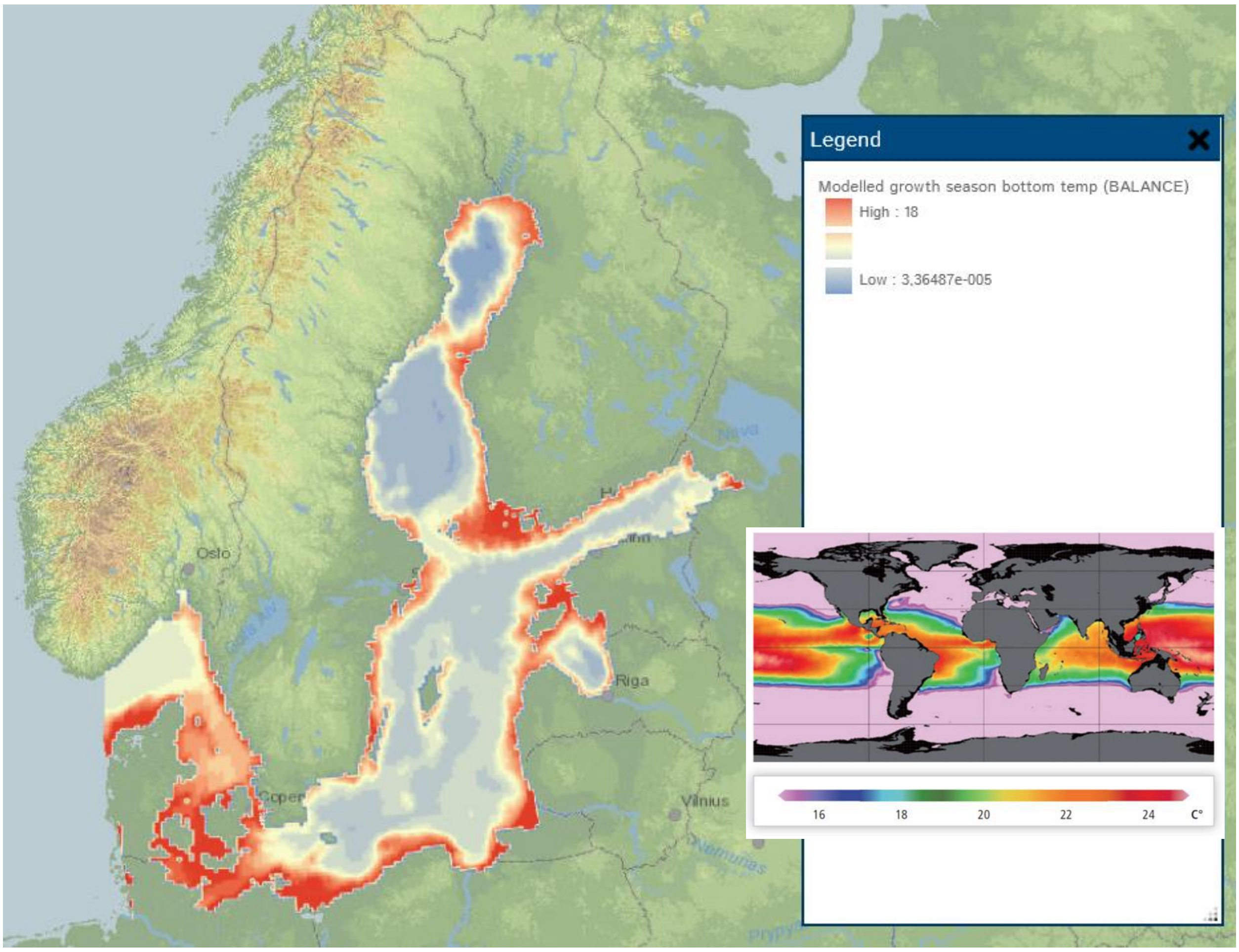


Figure 28: Model results for the average bottom temperature in the Baltic region in the plant growth season from April to September, Data Source: HELCOM, Small picture: worldwide average ocean temperature differences (°C) between 20 and 1,000 m water depth, Data Source: WORLD ENERGY COUNCIL. Compared to the worldwide energy potential, the Baltic Sea is probably not the first choice for establishing parks.

temperature shows significant variations over seasons and from year to year. One of the indicators is the sea ice extend that shows a huge difference in yearly extend. The water depth in the Baltic Sea has a significant impact on the temperature distribution as indicated in the map below. The northern part of the Gulf of Bothnia (Bothnian Bay) and the coastal zone down to the Åland Sea and the inner parts of the Gulf of Finland and Gulf of Riga usually become completely ice-covered in January. At depths more than 50 m the average annual temperature is 3-4 degrees Celsius. (Heino, 2013). OTEC typically requires a differential of about 20°C to work effectively meaning where cool water (~5°C) is drawn from depths of around 800–1000 m and surface water temperatures sit at a constant 25°C20. Consequently, its potential application is limited to between 35o latitude north and south of the equators (Schiffer, 2016) and thereby not applicable for the Baltic sea.

4.5.6 Biomass resources in the Baltic Sea region

Assuming a constant biomass production throughout the year, the annual biomass production is estimated to be ≈ 1.2 kg dry matter/m2 of sea surface. This equals 33 g of sequestrated nitrogen/m2 per year corresponding to the removal of at least 330 kg of nitrogen/ha by harvesting the naturally occuring species of algae and mussels established on nets and lines at sea. Using 25% of the available space in future Baltic Sea wind parks, more than 1,000,000 tonnes of biomass could be harvested yearly corresponding to a sequestration of at least 30,000 tonnes of nitrogen.

5 Spatial scenarios for 2030 and 2050

Global economic growth in the current system is directly related to rising demand for energy and renewable energy sources. Increasing demand for energy globally is likely to have a correlated effect on energy demand and supply in the Baltic Sea over the coming decades.

5.1 Ocean Energy

5.1.1 Baltic Sea

The resource (waves) is rather irregular and would need adaptation of the technologies that are currently under development. The ocean energy sector is struggling to prove their technologies in more energy dens waters with large demonstration projects and the learning curve is projected to have commercial products/arrays in the water around 2025-2030. This means that the developers are prioritizing other markets at the time and sees no interests in the Baltic sea before 2050.

There are a few universities (ie Klaipėda University, Latvia) that are interested in ocean energy and conducted sea trials in the Baltic sea. For innovation, small scale devices, components and subsystems temporary test sites can be needed. If technologies are to adapt to the Baltic sea resources, there needs to be parallel development/research on more efficient technologies. The permit process to conduct sea trial differs from each country and it might be easier to get a single permit for a unique test rather than to establish a test site.

5.1.2 Kattegat and Skagerrak

The resources for Skagerrak are mild and perfect for long term testing and good access to test specimens. The already existing sites (Islandsberg and Sotenäs Test Site) gives companies and researchers the possibilities to carry out test and validation. These sites have the capacity to accommodate several customers and up till today only a small portion has been used at times. There is no plans or interests from any ocean energy developer to deploy any ocean energy arrays at the west coast of Sweden, but the interest to be able to conduct component and sub systems trials is at large and those needs are accommodated by already existing areas.

5.2 Marine Biofuel

There need to be extensive research to scale up the production and to reduce costs. Before then, there is little needs for large areas in the marine spatial planning dedicated for algae production. The already existing R&D areas meet the future needs for different test scenarios on the technology side.

6 Conclusions

6.1 Ocean Energy

Wave energy is one form of renewable energy that is not yet widely known much less in use. Usually the wave energy is connected to large oceans with big waves and heavy swell. Inner seas or sheltered areas have not been investigated much, but they do have potential producing wave energy. Baltic Sea is a sheltered sea, but it has been calculated to have an energy potential of 24 Twh that could be used in coastal areas in Baltic Sea countries. In the Baltic Sea area, the wave conditions vary strongly between seasons and areas. The biggest basin of the Baltic Sea, the Baltic Proper, has the most severe wave climate in the Baltic Sea. Ice formation during winter times hinders the wave formation and limits the wave energy production. The choice of suitable kind of technology and adjusting it to local conditions, can give the optimal production of wave energy. There are few things that will to some extent decrease areas possible for exploitation, foremost shipping lanes, important fishing zones and marine protected areas as well as geo-physical conditions. However most likely these wave energy parks would be dispersing and suited with the environment.

Through interviews with developers they have little interest of deploying in the Baltic sea until they have proven their technology in other places where the resources are more challenging. Once the technologies have been proven they can move to the next stage and adapt their technologies for other types of resources and regional requirements. Until they 2050 they see no need for any areas to be reserved for ocean energy arrays. The only reason for ocean energy to take place in the work with spatial planning is the need for research and testing of component and small-scale prototypes.

6.2 Marine Biofuel

For seaweed farming, neither irrigation nor farmland is required. Another plus point is that manufacturing seaweed-based ethanol produces less greenhouse gases than the conventional ethanol procured from corn or wheat. Thus, seaweed farming is an environmentally friendly way to produce fuels in the coming years. Researchers are looking to mechanize the process for large-scale seaweed production. They will also have to find cost-effective renewable energy processes for drying seaweed or else the overall costs will shoot up. Success in large-scale production of seaweed-based biofuels would mean reduction of our excessive dependence on oil in the future. Although large-scale seaweed biofuel production is not yet a reality, millions are being invested in seaweed research around the world and there is hope that this novel technology will be widely used for biofuel production in the future. To meet the future demand for liquid fuels the marine areas for production will need to be rather large and probably be combined with large offshore wind parks or other aquaculture activities. In the Baltic Sea, Kattegat and Skagerrak there is little in literature that support a large-scale development and the needs regarding those areas. To get to large scale production extensive research on technologies that will help reducing the overall cost is needed. To test and demonstration of new techniques areas for marine research is a must. These areas need to be defined in the different regions since cultivation needs to come from regional specimens (this applies especially for the Baltic Sea).

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