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UTILISATION OF WAVE POWER IN THE BALTIC SEA REGION

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1. Introduction

Renewable energy is the important issue at moment. It is hoped, that the renewable energy gives one solution to increasing energy demand and has also a positive effects on climate change. Wave energy is one source of renewable energy, which has not yet been exploited to a large extent. The potential of wave energy is estimated to be about the same as the economic potential of wind or hydropower in the world (10000-15000 TWh). The development of wave energy has been a difficult process though. It is more expensive to carry out the experiments and model testing off-shore and in harsh conditions than on shore.

Wave energy has a potential as a truly renewable, sustainable energy source also in the Baltic Sea. Even though the main focus has been in the great oceans, a large portion of the world potential in wave energy resources are found in sheltered and calmer seas. In the Baltic Sea alone, the potential is calculated to be 24 TWh (Bernhoff et al. 2006). The wave power is suitable for local electricity production in coastal areas. It can also be an answer for energy security in the archipelago and coastal areas.

This report is compilation of information from different sources. It starts from the global view about the ideas of energy use and demand, and then goes to the important role of the European Union. Next it takes a peak to renewable energy forms, before concentrating on wave energy. From wave energy it moves to Baltic Sea region, it characteristics and the regions potential to generate wave energy.

1.1. The global energy situation

The world's energy demand is increasing, but at the same time the traditional resources are diminishing. The World Energy Council has estimated that coal is the most abundant of the fossil fuels. Coal has reserves to production ratio of about 128 years, compared with 54 for natural gas and 41 for oil (WEC 2010). The global climate change creates also a challenge to energy use and especially to fossil fuel use. The global use of fossil fuels (coal, oil and gas) is dominating energy supply, leading to a rapid growth in carbon dioxide emissions. The U.N. Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report concluded that "Most of the observed increase in global average temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." Greenhouse gas emissions need to be controlled, and in the world of increasing energy demand the renewable energy sources seem to be the best solution. In spite of these facts all countries and actors are not willing to change direction.

International Energy Agency's Executive Director Maria van der Hoeven highlighted the actions that should be done. She called on countries to step up efforts to avert climate change, noting that to do so requires addressing their energy security concerns in a sustainable manner. Ms. Van der Hoeven urged countries not to wait for a comprehensive deal on climate but rather to act now to meet growing demand for energy with secure, low-carbon solutions. She noted also that while the focus has been for years on how energy will affect climate, it is time to begin studying how changes in climate will affect energy systems and, by extension, energy security. (IEA 2011a.)

There are also other recent events that are worrying many. For example the uprising in the Arab countries and the catastrophe in Fukushima nuclear power can change the developments of energy use. Michael T. Klare (2011) states, that the world economy is structured in a way that standing still in energy production is not an option. Even if usage of energy grows somewhat more slowly than projected, any failure to satisfy the world's requirements produces a perception of scarcity, which also means rising fuel prices. It is against this backdrop that Klare remarks three crucial developments of 2011 that are changing the way we are likely to live on this planet for the foreseeable future.

The first and still most momentous of the year's energy shocks was the "Arab Spring" in the greater Middle East. For example Libyan oil production, normally averaging approximately 1.7 million barrels per day, was fallen to near zero. When it comes to the future availability of oil, it is impossible to overstate the importance of this spring's events in the Middle East, which continue to thoroughly rattle the energy markets. According to all projections of global petroleum output, Saudi Arabia and the other Persian Gulf states are slated to supply an ever-increasing share of the world's total oil supply as production in key regions elsewhere declines. (Klare 2011.)

In terms of the energy markets, the second major development of 2011 occurred on March 11th when an unexpectedly powerful earthquake and tsunami struck Japan. It devastated four nuclear plants in Fukushima. The huge loss of electric generating capacity force Japan to import oil and natural gas. In addition the disaster at Fukushima has had a domino effect, causing energy officials in other countries to cancel plans to build new nuclear plants or extend the life of existing ones. (Klare 2011.)

The third major energy development of 2011, less obviously energy-connected than the other two, has been a series of persistent droughts gripping many areas of the planet. Typically, the most immediate and dramatic effect of prolonged drought is a reduction in grain production, leading to higher food prices. But drought has an energy effect as well. It can reduce the flow of major river systems, leading to a decline in the output of hydroelectric power plants, as is now happening in several drought-stricken regions. By far the greatest threat to electricity generation exists in China. There has been a significant decline in hydropower and severe electricity shortages throughout much of central China. (Klare 2011.)

There are many indications that lead the way towards renewable energy sources. The development and usage of green energy forms could have a solution to many problems that the world is facing today and in the future. As well as having a large potential to mitigate climate change, renewable energy can provide wider benefits. Renewable energy may, if implemented properly, contribute to social and economic development, energy access, a secure energy supply, and reducing negative impacts on the environment and health (IPCC 2011). The European Union has had an active role in the development of renewable energy.

1.2. Green energy in the European Union

For several years now the European Union has been committed to tackling climate change both internally and internationally and has placed it high on the EU agenda, as reflected in European climate change policy. According to scientific research, the currents levels of CO_2 and methane in the atmosphere are the highest they have been for 650 000 years, which causes a significant acceleration of the greenhouse effect.

To stabilize global warming at an average of 2° Celsius, global emissions must fall by almost 50 % compared to 1990 levels by 2050, which implies a 60 to 80 % reduction by most developed countries by 2050 and a gradual but significant effort made by developing countries. (Europa environment 2011.)

Europe's demand for energy is increasing in an environment of high and unstable energy prices. Greenhouse gas emissions are rising and the energy sector is one of the main emitters of greenhouse gases. Natural reserves of fossil fuels such as oil and gas are not concentrated in the area of EU. Climate change along with an increasing dependency on energy imports are only a few of the risks the European economy is facing today. The energy sector is the fuel of Europe´s economic engine, hence having the right approach is important. (EREC 2010.)

Energy prices are rising world-wide. The Energy Roadmap 2050 of the European Commission demonstrates that while prices will rise until 2030 or so, new energy systems can lead to lower prices after that. The clear message is that investments will pay off, in terms of growth, employment, greater energy security and lower fuel costs. The transformation creates a new landscape for European industry and can increase competitiveness. (EC 2011.)

1.2.1 Steps towards renewable energy use in Europe

In 2005, the Commission laid the foundations for an EU strategy to combat climate change. In 2007 strategy on climate change for 2020 (COM(2007)2, Limiting Global Climate Change to 2 degrees Celsius The way ahead for 2020 and beyond) was made. (Europa environment 2011.)

With the agreement in 2009 on the Energy and Climate Package which contains the European Directive on the promotion of the use of energy from renewable sources with its binding target of at least 20% renewable energy in final energy consumption by 2020, the EU has made a strong and ambitious commitment towards renewable energy. The Directive (2009/28/EC) on renewable energy set ambitious targets for all Member States. By the end of 2009 the renewable energy sector secured more than 10% of Europe's final energy consumption, provided one-quarter of the EU's binding 20% greenhouse gas reduction target. CO_2 emissions were reduced by about 340 million tons against 1990 levels in the EU (EREC 2010).

In 2010 The European Renewable Energy Council published a report, RE-Thinking 2050. The objective of the report is to set a long-term vision for the energy system in the European Union, one which is entirely based on renewable energy sources. The report outlines a way towards 2030 and presents a vision for 2050. In addition, it analyses the economic, environmental and social benefits likely to accompany such a transition and points out the necessary framework conditions to make this vision become reality. (EREC 2010.)

The EU is now committed to reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050 in the context of necessary reductions by developed countries as a group. The energy sector produces the lion's share of man-made greenhouse gas emissions. Therefore, reducing greenhouse gas emissions by 2050 by over 80% will put particular pressure on energy systems. If, as seems likely, global energy markets become more interdependent, the EU energy situation will be directly influenced by the situation of its neighbours and by global energy trends. The results of the future scenarios depend notably on finalising a global climate deal, which would also lead to lower global fossil fuel demand and prices. (EC 2011.)

Wind, solar, hydropower, ocean and geothermal energy do not contain any fossil carbon atoms to form climate damaging CO_2 during combustion. The European Union Commission considers that the renewable energy is a stimulus for economic growth. Moreover, a strong emphasis on “sustainable development” must lie at the heart of any economic, environmental and social activity. (EREC 2010.) Many renewable technologies need further development to bring down costs. There is a need to invest in new renewable technologies, such as ocean energy and concentrated solar power and 2nd and 3rd generation biofuels. (EC 2011.)

In the last fifteen years or so, most of the R&D activity in wave energy has been taking place in Europe, largely due to the financial support and coordination provided by the European Commission, and to the positive attitude adopted by some European national governments (Falcao 2010).

1.2.2. New attitudes and demand for renewable energy

In the 2007 Special Eurobarometer on energy technologies EU citizens were asked about their attitudes towards different energy sources. The survey clearly states that EU citizens are most in favour of renewable energy sources, while the use of fossil and in particular nuclear energy is opposed by many (EREC 2010 s.43, EC). The awareness of climate changes and its effects is growing. People want to influence themselves on important issues. The demand for renewable, green energy is growing and people are willing to pay more to get it.

The U.N. Intergovernmental Panel on Climate Change (IPCC) has produced a comprehensive report on Renewable Energy Sources and Climate Change Mitigation. The paper predicts that the costs of renewable energy will fall in coming years due to technological advances. At the same time, solar, wind and other clean energy sources will surge in demand and eventually account for the vast majority of overall energy use. Increased demand is likely to continue “even without new measures to promote a shift from fossil fuels”, as part of the fight against climate change. (IPCC 2011.)

Energy security concerns that may be characterized as availability and distribution of resources, as well as variability and reliability of energy supply, may also be enhanced by the deployment of renewable energy. As renewable energy technologies help to diversify the portfolio of energy sources and to reduce the economy’s vulnerability to price volatility and redirect foreign exchange flows away from energy imports, they reduce social inequities in energy supply. Current energy supplies are dominated by fossil fuels (petroleum and natural gas) whose prices have been volatile with significant implications for social, economic and environmental sustainability in the past decades, especially for developing countries and countries with high shares of imported fuels. Climate change mitigation is one of the key driving forces behind a growing demand for renewable energy technologies. In addition to reducing greenhouse gas emissions, renewable emergy technologies can also offer benefits with respect to air pollution and health compared to fossil fuels. (IPCC 2011.)

The decisions taken today will have an impact on the forty years to come. It is now time to decide whether to continue the polluting energy pathway of the past or to progress to one based on clean, sustainable and locally available renewable energy sources. Renewable energy technologies are available, reliable and capable of providing all energy services from transport solutions to heating and cooling as well as electricity generation. It is a matter of political will and of setting the course today for a sustainable energy future tomorrow. (EREC 2010.)

2. Renewable energy sources

2.1. Hydro power

Hydro power is one of the oldest known energy sources. Currently the energy potential of rivers and rapids is not any more used mechanically; instead it is used for electricity production via water turbines. Water turbine is a good example of mature technology, where significant technological developments are not expected. Hydro power is the dominant source of renewable energy worldwide, producing 3 252 TWh, which is equivalent to 16.2% of global electricity production in 2009 (IEA 2011b). The share of hydro power is important also in Sweden and Finland. Hydro power projects can have significant environmental and social impacts, and analysing the balance between the benefits and effects can be a difficult task.

The efficiency of hydro power plants is often increased by regulation of the water system; i.e. dams and water reservoirs. Water is stored in reservoirs and fed in turbines for subsequent changes in electricity needs. However, the amount of annual hydropower production varies quite a lot due to differences in annual precipitation. In addition to large-scale centralised hydropower plants there is also some small-scale and micro hydro power in use, which is characterised my hydropower plants with low efficiency (typically less than 10 MW) for local use and minimal or lacking water regulation. (Luukkanen & al. 2009.)

2.2. Solar

Solar energy is the most abundant permanent energy resource on earth and it is available for use in its direct (solar radiation) and indirect (wind, biomass, hydro, ocean etc.) forms. The total annual solar radiation falling on the earth is more than 7 500 times the world's total annual primary energy consumption of 450 EJ. (WEC 2010.)

Nowadays, an extremely large variety of solar technologies are available, and photovoltaic (PV) have been gaining an increasing market share for the last 20 years, but global generation of solar electricity is still small compared to the potential of this resource. Great advances have been made in the development of solar energy technologies. Efficiencies have been improved and costs have been brought down by orders of magnitude. The technologies have become cost-effective for some applications. However, they are still too expensive for other applications such as grid electricity, unless environmental costs are accounted for or incentives are given for these technologies. (ibid..)

At present, the markets for solar PV technologies are increasing at a rate of more than 35% per year and solar thermal power growth is expected to be even higher. However, these applications are starting from a very small or negligible base. Therefore, an even higher growth rate would be needed to reach the levels envisioned for the future. (ibid..)

From 2000 to 2010, in terms of the annual rate of market growth, solar PV was the fastest-growing power technology worldwide. Estimates suggest that cumulative installedcapacity of solar PV reached roughly 40 GW at the end of 2010, up from 1.5 GW in 2000 (IEA 2011c). In the future the trends for photovoltaic systems are expected to be positive, with global yearly electricity generation between 1,383 and 2,584 TWh in 2050. (IEA 2008.)

2.3. Wind

Wind energy has been utilised by man for thousands of years, initially to provide mechanical energy and now to provide electricity. It is available virtually everywhere on earth, although there are wide variations in wind strengths. The rapid growth of wind energy may be demonstrated by noting that the projection for 2010 set out in the European Commission's White Paper on renewable energy (EC, 1997), was 40 GW. That was 16 times the capacity in 1995, but the target was realised by 2005 and by late 2009, European capacity was over 72 GW. (WEC 2010.)

Wind energy is a mature and proven technology, with mature markets around the globe and an increasingly globalised manufacturing industry. Wind energy is a reliable and increasingly cost competitive source of clean energy with the potential for further cost reductions. Apart from learning-induced cost reductions, the increased competition with Asian manufacturers entering the market will put downward pressure on turbine prices. (IEA 2011c.)

Several studies have shown that wind plants 'repay' the energy used during construction by about 6 months or less, and so electricity generated after that time realises substantial emission savings (WEC 2010). There is also a specific offshore wind industry developing. Offshore wind has significant potential. The advantages of working off shore (higher wind speeds and fewer siting constraints) will allow larger machines and wind farms, which should improve the economics. These advantages are balanced by the higher costs of installation, more severe operating conditions, and impacts of unfavourable weather conditions on access for construction and maintenance. New larger turbines designed to operate under the challenging conditions are under development, along with foundations and platforms that will allow access to deeper sea areas. Although generation costs are currently high, significant potential exists for cost reduction. (IEA 2011c.)

2.4. Bioenergy

The term bioenergy denotes the use of vegetable matter as a source of energy. Fuel wood and charcoal are the traditional wood forest products, and even today almost half of all of the forest harvest is for energy, with the remainder for industrial use. Charcoal is produced by the thermal conversion of wood and other biomass. The largest secondary transformation of biomass after charcoal production is in the electricity sector. For many years biomass processing industries such as sugar, wood products and chemical pulping (black liquor) have installed combined heat and power (CHP) plants. Many of these have been relatively low steam temperature installations, with only sufficient electricity to meet the plant processing needs (WEC 2007).

At present, forestry, agricultural and municipal residues, and wastes are the main feedstock for the generation of electricity and heat from biomass. In addition, very small shares of sugar, grain, and vegetable oil crops are used as feedstock for the production of liquid biofuels. Today, biomass supplies some 50 EJ globally, which represents 10% of global annual primary energy consumption. This is mostly traditional biomass used for cooking and heating. (WEC 2010.)

Biomass can make a substantial contribution to supplying future energy demand in a sustainable way. It is presently the largest global contributor of renewable energy, and has significant potential to expand in the production of heat, electricity, and fuels for transport. (ibid..)

Transport biofuels are currently the fastest growing bioenergy sector, receiving a great deal of public attention. However, today they represent only 1.5% of total road transport fuel consumption and only 2% of total bioenergy. They are, however, expected to play an increasing role in meeting the demand for road transport fuel, with second generation biofuels increasing in importance over the next two decades. (ibid.)

The main barriers to widespread use of biomass for power generation are cost, low conversion efficiency and feedstock availability. Most important are the lack of internalisation of external costs in power generation and effective policies to improve energy security and reduce CO_2 emissions. In the long term, bio power potential will depend on technology advances and on competition for feedstock use, and with food and fiber production for arable land use. (IEA 2007b.)

2.5. Ocean energy

Five different ocean energy technologies are under development and aim to extract energy from the oceans. These include tidal power, marine currents, wave power, temperature gradients and salinity gradient. None of these technologies is widely deployed as yet. According to International Energy Agency the wave power has the biggest potential (IEA 2011).

3. Wave energy

Wave energy can be considered as a concentrated form of solar energy, where winds generated by the differential heating of the earth pass over open bodies of water, transferring some of their energy to form waves. The amount of energy transferred and hence the size of the resulting waves depends on the wind speed, the length of time for which the wind blows and the distance over which it blows (the 'fetch'). In this way, the original solar power levels of typically ~ 100 W/m² can be transformed into waves with power levels of over 1,000 kW per metre of wave crest length. (WEC 2010.)

Waves lying within or close to the areas where they are generated (storm waves) produce a complex, irregular sea. These waves will continue to travel in the direction of their formation even after the wind dies down. In deep water, waves lose energy only slowly, so they can travel out of the storm areas with minimal loss of energy as regular, smooth waves or 'swell' and this can persist at great distances from the point of origin. Therefore, coasts with exposure to the prevailing wind direction and long fetches tend to have the most energetic wave climates, such as the western coasts of the Americas, Europe, Southern Africa and Australia/New Zealand. (ibid.)

In addition to the large size of the resource and the lack of associated greenhouse gas emissions, wave energy has several important advantages. Compared with e.g. wind and solar power the waves have a higher energy density and more predictable occurrence. Outside the tropics, storms are usually more intense and frequent during winter, which results in wave power levels being higher in that season. Therefore wave energy provides good seasonal load following for those regions where peak electricity demand is produced by winter heating and lighting requirements (e.g., northern Europe, western Canada and northwest USA). Secondly wave energy is predictable for one to two days ahead, because satellites can measure waves out in the ocean that will later impact on devices around the coast. This predictability will allow for less spinning reserve than is often required to support more intermittent renewable energy sources. (WEC 2007; WEC 2010.)

The wave energy has a global potential in the range of wind and hydropower. Wave power along the European west coast has been estimated to be able to cover all of the Western European electric energy consumption. However, wave energy has to face various difficulties as in many countries. There is a high cost associated with obtaining permits and carrying out environmental impact assessments. Moreover, once deployed in free energy markets, wave energy has to compete with established renewable energy technologies that have benefited from billions of dollars of cumulative investment. (WEC 2007; Luukkanen et al. 2009.)

In general, the development of wave power, from concept to commercial stage, has been found to be a difficult, slow and expensive process. Although substantial progress has been achieved in the theoretical and numerical modeling of wave energy converters and of their energy conversion chain, model testing in wave basin — a time consuming and considerably expensive task — is still essential. The final stage is testing under real sea conditions. In almost every system, optimal wave energy absorption involves some kind of resonance, which implies that the geometry and size of the structure are linked to wavelength. For these reasons, if pilot plants are to be tested in the open ocean, they must be large structures. The high costs of constructing, deploying, maintaining and testing large prototypes under sometimes very harsh environmental conditions, has hindered the development of wave energy systems; in most cases such operations were possible only with substantial financial support from governments. (Falcao 2010.)

3.1. Wave energy technologies

Many wave energy devices are at the R&D stage, with only a small range of devices having been tested at large scale or deployed in the oceans. This slow rate of progress is due to the fact that wave energy devices face a number of design challenges, among which the variability in wave power intensity and wave direction. (WEC 2007.)

To operate its mechanical and electrical plant efficiently, a wave energy device must be rated for wave power levels that occur much of the time (e.g. in the UK this would be 30-70 kW/m). However, the device also has to withstand extreme waves that occur only rarely and these could have power levels in excess of 2 000 kW/m. This poses a significant challenge, because it is the lower power levels of the commonly-occurring waves that produce the normal output of the device, while the capital cost is driven by the civil structure that is designed to withstand the high power levels of the extreme waves. (ibid..)

Waves vary in height and period from one wave to the next and from storm to calm conditions. While the gross average wave power levels can be predicted in advance, this inherent variability has to be converted to a smooth electrical output if it is to be accepted by the local electrical utility. This usually necessitates some form of energy storage. Normally, offshore waves travel towards a wave energy device from a range of directions, so a wave energy device has to be able to cope with this variability either by having compliant moorings (which allow the device to point into the waves) or by being symmetrical. Another approach is to place the wave energy device close to the shore, because waves are refracted as they approach a coastline, so that most end up travelling at right angles to the shoreline. The relatively slow oscillation of waves (typically at ~ 0.1 Hz) has to be transformed into a unidirectional output that can turn electrical generators at hundreds of rpm, which requires a gearing mechanism or the use of an intermediate energy transfer medium. (ibid..)

Different devices have different solutions to these challenges. At least 100 separate technologies are represented by the wave energy devices currently being developed. There are various ways of categorising these devices. One way is to divide them in six different device types; point absorbers, oscillating water columns, flap/surge devices, attenuators or contouring devises, overtopping devises and others. (WEC 2010.)

3.1.1. Point Absorber

This is a buoy that is small in size 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 some kind of 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. Seabased's Linear Generator has a buoyant surface float attached via a flexible connector to a unit on the sea bed. The movement of the float is converted directly into electricity using a linear generator. (WEC 2010.)

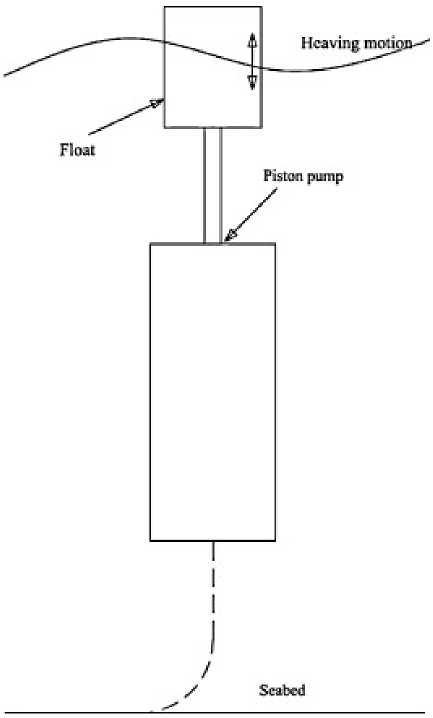

Figure 1. The Wavebob point absorber (Zabihian & Fung 2011).

3.1.2. Oscillating Water Column (OWC)

An 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. (WEC 2010.)

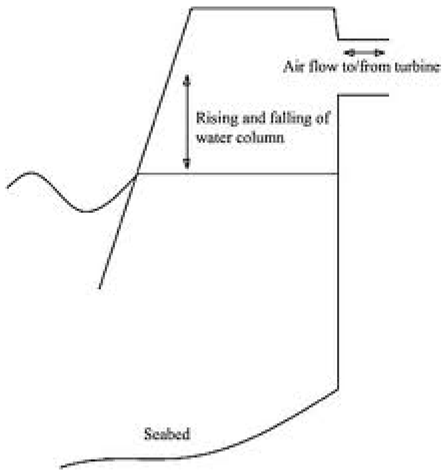

Figure 2. Sketch of oscillating water column wave energy converter (Zabihian & Fung 2011).

3.1.3. Surge Devices

These 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 actually deployed vary considerably. (WEC 2010.)

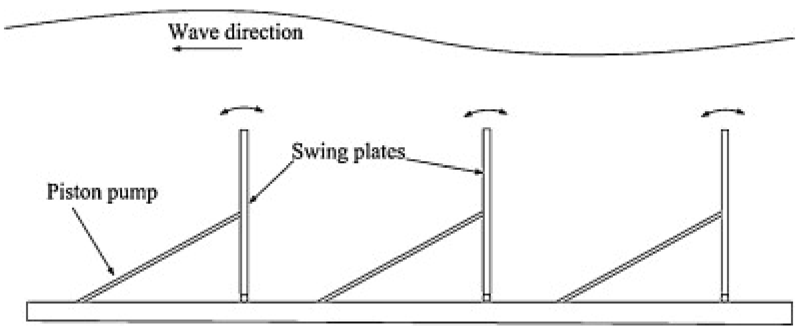

Figure 3. Sketch of the Wave Roller system (Zabihian & Fung 2011).

3.1.4. Attenuator/Contouring Devices

These 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. (WEC 2010.)

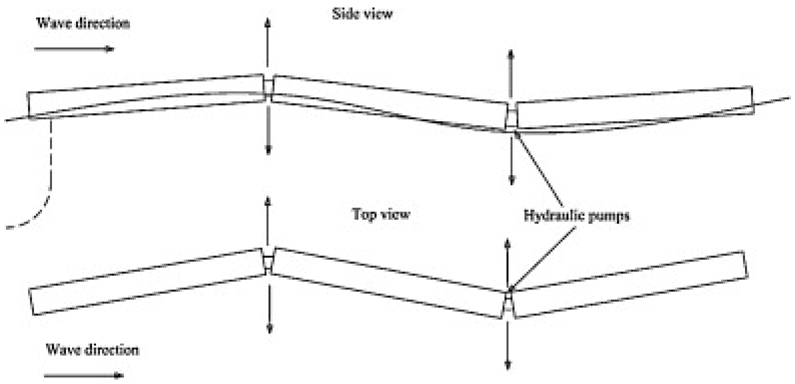

Figure 4. The Pelamis wave energy converter is attenuator device (Zabihian & Fung 2011).

3.1.5. Overtopping Devices

These rely on using a ramp on the device to elevate part of the incoming waves above their natural height in order to fill a raised reservoir, from which the seawater is allowed to return to the sea via low-head turbines. (WEC 2010.)

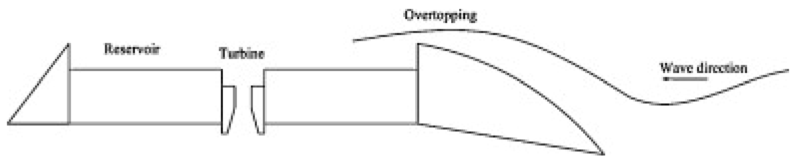

Figure 5. Sketch of one type of overtopping device, the Wave Dragon (Zabihian & Fung 2011).

3.1.6. Wave energy device used in project WESA

In project WESA Seabased's Linear Generator is used. This technique is well suited for the wave climate of the Baltic Sea. The wave energy converter and the measurement equipment that goes into this project is the responsibility of Uppsala University. However, the converter has been developed and manufactured by Seabased AB, a commercial spin-off company established in 2001 from the research at Uppsala University.

Seabased’s Linear Generator has a buoyant surface float attached via a flexible connector to a unit on the sea bed. The movement of the float is converted directly into electricity using a linear generator.

Seabased's wave power technology utilizes the water motion in waves to directly drive the wave power plants. The active element is a unique directly driven permanent magnet linear generator (Figure 1.). The generator is specially designed to take advantage of the slow movement of the waves that is transferred to it via a buoy (point absorber) on the ocean surface. The buoy action is transferred directly to the generator with no intermediate mechanical gearing since the generator is optimized to output high power even at slow speeds. The movement of the waves (about 15 wave cycles/min) causes the translator (corresponding to the swiftly turning rotor of a conventional generator) to move up and down within the stator, thus converting the kinetic energy of the wave to electric energy. Very powerful neodymium-iron-boron magnets are mounted on the translator. They create an alternating magnetic field which penetrates the stator windings. The stroke length of the translator is limited by end stops at the top and bottom. (Seabased AB 2009).

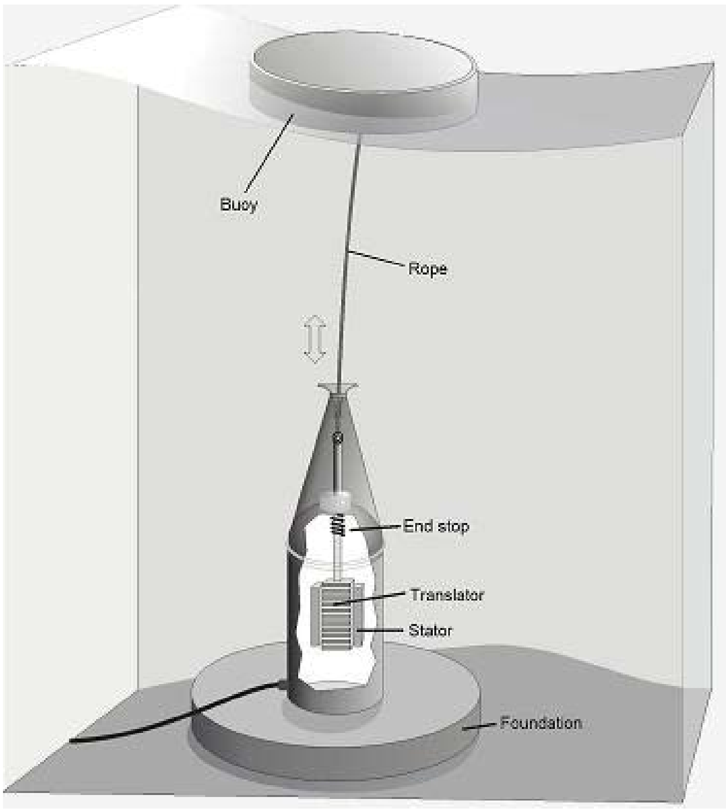

Figure 6. Seabased’s linear generator (Seabased Ab).

The generator capsule is bolted to a concrete foundation that stands on the bottom of the sea. There it is held in place and sheltered from the large forces which can occur at the surface. There is no need to prepare the sea bottom using this concept. The size and weight of the foundation is based on local wave and seabed conditions. The foundation of a wave energy converter of this kind has shown to have the effect of an artificial reef, offering a possibility for recuperation of the marine life and shelter form excessive over-fishing. (WESA 2011).

This kind of wave energy converter, of the model at Hammarudda, has a rated power production capacity of 20 kW. Within an area of 1 km^2 some 1000 units can be fitted. This wave energy park would have a theoretical electrical production of 20 MW. After an expected life time of approximately 20 years the power plant will be recycled. (WESA 2011).

3.2. Environmental aspects

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. There are some assessed environmental impacts of Seabased's wave power installation: The occupied seabed area from the foundations 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. There will be an operation noise from the transformer in the substation, a buzz with a frequency of 50 Hz. This sound is not likely to be heard above the background noise of the ocean. (Seabased 2009.)

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 a number of sessile and motile organisms. (Langhamer et al. 2010.)

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 favor 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. (ibid..)

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. (ibid..)

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. (ibid.)

Grecian et al. (2010) have described the potential threats and benefits of wave energy devices to marine birds. Direct negative impacts include risk of collision, disturbance, displacement and redirection during construction and operation. Above water collision risk is quite low, because of the low profile of the wave energy devices. Conversely they could pose a novel threat of underwater collision. Devices may alter the oceanographic processes and have an impact on food availability, which indirectly effects on marine birds. Direct positive effects may include provision of roosting sites, and indirect effects may include pray aggregation. The wave power areas could also act as protected areas, what could also bring more opportunities to marine birds.

3.3. Economic aspects

Wave energy can be used locally in coastal areas and in the archipelago. In those remote areas the transfer of energy from mainland can be difficult and also expensive. Wave energy can prove to be very feasible way of energy production in the archipelago and coastal areas. Anyways the trend in energy production is towards local and green energy production.

Since the wave energy technology is immature, the predicted generating costs for the first wave energy devices are high. Follow-on schemes should benefit from improved savings in costs, through design optimisation and mass production, as well as increases in the device performance. It is estimated that the costs for initial designs are about four times higher than costs for mature devices. (WEC 2010.)

A wave energy park built using Seabased's concept can be expanded in stages. Electricity can be generated and delivered to the grid with only a few units installed. Consequently cost recovery can begin long before the entire wave energy park is completed. Seabased's generators have a nominal power of 10-50 kW. The installed power of a medium large wave energy park with 2000 generators, with an average power of 10 kW per generator, is 20 MW with an expected production of 50 GWh per year. Using Seabased's system electrical energy is expected to be generated at very competitive costs with no need for long term subventions or tax reductions. The global potential for wave energy is calculated to be 10 000-15 000 TWh per year. This is comparable to the economic potential for hydro power across the world. In the Baltic Sea alone, the potential is calculated by Bernhoff at al. (2006) to be 24 TWh. (Seabased 2009.)

The energy production of linear generator depends on the significant wave height, the size of the buoy and the resistance. To gain the maximal production all these need to be in balance. Energy present in an ocean wave is dependent upon both its period and its height. It is important to know the local wave climate to be able to get most out of it. The wave energy device must be adapted to the local wave climate. The size of the buoy determines the buoyancy and the lifting force. Adjusting the resistance effects the energy production. Finding the optimal adjustments for specific location needs also some time for testing it.

Investments in renewable energy plants normally only take standard economic key figures into account, such as installed rated power, the market price of energy and the interest rate, when considering the economic aspects. Leijon et al. (2003) propose that the degree of utilisation, i.e. the ratio of yearly produced energy in the installation to the installed power, must be included due to its significant impact on the present value of the investment. A site with a limited average wave height could be of economic interest if the utility factor for the installation is high, since the investment cost (associated with the power installed) can be better adjusted to conditions at the particular site. In the case of wave power from the Baltic Sea with its limited variation in wave height (and limited average wave height), this indicates that the economic potential is best for smaller units.

Ocean wave energy has the potential to contribute large amounts of renewable energy to the world's societies. In order for the wave energy converters to be competitive, they have to be adapted to the local wave climate. The more detailed knowledge one has of the wave climate of a particular site, the easier it is for developers of wave energy systems to optimize the technology and make it competitive. (Waters et al. 2009.)

4. Baltic Sea

4.1. General

The Baltic Sea is a relatively shallow inland sea, bounded by the coastlines of Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russian Federation and Sweden. The Baltic Sea is the world's largest brackish water sea (268.000km^2), being comparatively shallow with an average depth of only 55m and with a maximum depth of 450 m. 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. The water of the Baltic Sea is a mixture of ocean water and fresh water brought by numerous rivers. The shallow sounds between Sweden and Denmark provide a limited water exchange with the North Sea. The Baltic Sea can be divided in different parts based on the forms of the sea bottom (Figure 2.).

Annual mean temperature increases gradually from north and east to south and west. 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.

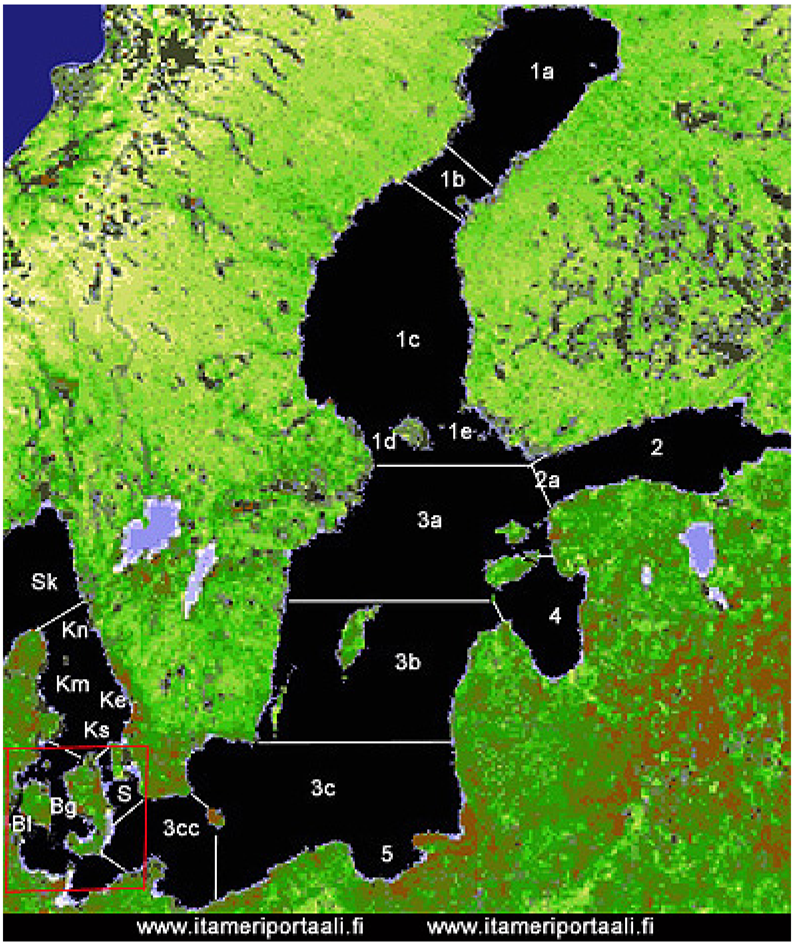

Figure 7. Different parts of the Baltic Sea: 1 Botnia Bay, 2 Gulf of Finland, 3 Baltic Proper, 4 Gulf of Riika and 5 Gulf of Gdansk

The Baltic is a 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

4.2. Water level

Tidal forces don't have such an effect in Baltic Sea than in larger ocean. Tide cause only few centimetres of water level variation in Finnish coastal areas. Most important factors influencing water level in the Baltic are atmospheric pressure, wind, currents through the Danish straits and, during winter, the extent of ice cover and its effects.. Wind piles up water to certain areas of the Baltic, especially inner bays, and the highest amplitudes of water level can be found in these areas. Wind can also have local effects. High atmospheric pressures push water surfaces down. A density gradient of one mill bar equals to one centimetre of water, normal changes in atmospheric pressures can thus shift water levels tens of centimetres. Water flow in and out of the Danish straits changes the total volume of Baltic water and thus to the water level all around the Baltic. Currents are caused by water level differences between the Atlantic and the Baltic and strong winds in the area. (Baltic Sea Portal 2012.) The changes in water level can also effect the harvesting of wave energy and of course the technology used for that.

4.3. Wave climate

The knowledge and understanding of the local wave climate is important when harvesting the wave energy. In order for the wave energy converters to be competitive, they have to be adapted to the local wave climate. The more detailed knowledge one has of the wave climate of a particular site, the easier it is for developers of wave energy systems to optimize the technology and make it competitive. (Waters et al. 2009.)

The Baltic Sea is located in a region where the warmer westerly and the colder polar easterlies converge and produce a belt of low pressures. This gives a large variation in the wind field. A characteristic feature is the seasonal variation, with higher wind speeds in wintertime and lower wind speeds in summer. The dominant waves are 0.5 m lower and 1 s shorter during summer than in the winter period. The largest seasonal differences of high and long waves are found at the Gotland Deep. The lower waves in the summer and higher waves in the winter are obvious and reflect the same variation in the wind field. (Jönsson et al. 2002.)

In a relatively small Baltic Sea, the local geographic features affect to the wave conditions. The archipelago and the irregular shoreline in the northern Baltic Sea affect the wave growth and propagation by sheltering or changing the fetch over which the waves grow. Another specific feature that affects the wave growth in the Baltic Sea is ice cover in winter. (Tuomi et al. 2011.)

The wave conditions in the Baltic Sea area vary strongly between seasons and areas. The lowest mean and maximum modeled significant wave heights are found in the Gulfs of Finland and Riga but quite often also in the Bothnian Bay and Kattegat. Significant wave heights over 4 m were modeled in the hindcast in the Bothnian Bay. (Jönsson et al. 2002.)

The Bothnian Bay , the Gulf of Finland, and the Gulf of Riga have quite similar wave climates, the Bothnian Bay has a slightly more severe wave climate than the other gulfs. The differences in the wave climate in the basins of the Baltic Sea are considerable but they can be explained by the sizes and the shape of the areas. Also the ice conditions and prevailing wind directions are explaining the differences. The prevailing wind direction is southwest or south in the northern Baltic Proper, the Bothnian Sea and the Bothnian Bay. In the Gulf of Finland the prevailing wind direction is southwest or west. However, the wind direction in high wind situations may differ from these. (Tuomi et al 2011.)

4.3.1. Wave formation

When the wind begins to blow over a calm water surface, the water is set flowing. The whirls in the flow cause pressure differences that break the flat surface. The wind catches these tiny "wrinkles" and starts growing them up. Small waves are steep in the beginning, but in the course of developing they grow faster in length than in height. The water surface is not just a passive playground of the wind: as a moving surface with waves of different sizes it modifies the wind field that is generating it. (Baltic Sea Portal 2012.)

The most important factors that control the growth of the waves are the wind speed, the wind duration (how long the wind blows) and the fetch. The fetch is the distance from the upwind shore, or more generally, the distance over which the wind blows. When the wind duration is not limiting the growth, the fetch determines the wave height. The geometry and the depth of the water basin have also their effects on the evolution of waves. When the depth is less than a half of the wavelength, the waves begin to feel the bottom; wavelength is the distance between two successive wave crests. (ibid..)

When the wind calms down, the propagation speed of the waves is faster than the wind speed, and the wind can no longer feed energy to the waves. Smaller waves dissipate and the waves turn into swell. Waves that have propagated from a distant storm are also called swell. In the oceans swell can propagate thousands of kilometers without dissipating before entering shallow water near the coast where they break causing sometimes impressive breakers. (ibid..)

4.3.2. Significant wave height

Wave height is the vertical difference between the wave through and the wave crest. The wave field is a combination of waves of different height, length and directions and the significant wave height is a useful way to describe the sea state. The significant wave height is calculated from the energy spectrum of the measured waves. The wave spectrum tells how the energy is distributed to different wave lengths and directions. The significant wave height corresponds also the average of one third of the highest waves in a measured wave record. The highest individual wave in a wave field can be nearly two times higher than the significant wave height. (Baltic Sea Portal 2012.)

Even if the Baltic Sea is small compared with the oceans, it is able to generate waves of respectable heights. The biggest basin of the Baltic Sea, the Baltic Proper, has the most severe wave climate in the Baltic Sea. During a storm on 22 December 2004, the significant wave height in northern Baltic Proper reached 8.2 meters and the highest individual wave height was 14 meters. (ibid..)

The highest measured significant wave height off Helsinki in the Gulf of Finland is 5.2 meters. It was measured on 15.11.2001 and the highest individual wave reached 9 meters. At this location, both easterly and westerly winds are able to generate waves this high, but much higher they are not expected to grow due to the narrow shape of the Gulf of Finland. In the southern Bothnian Sea, a significant wave height of 5.5 meters, measured in 1970s, is still holding the record. The highest individual wave was 10 meters. The highest measured significant wave height in the Bay of Bothnia is 3.1 meters with a highest individual wave of 5.6 meters. (ibid..)

In 2010 waves were measured in eight locations in the Baltic Sea and Skagerrak (Figure 2.). Finnish Meteorological Institute (FMI) made real time wave measurements at two locations in the Baltic Sea, in the Northern Baltic Proper (station Northern Baltic Proper) and in the Gulf of Finland (station Helsinki). The northern parts of the Baltic Sea freezes every year. The length of the measuring periods varies every year depending on the extend of the ice cover. The Swedish Meteorological and Hydrological Institute (SMHI) made wave measurements at four locations, in the Southern Bothnian Sea (station Finngrundet), in the Northern Baltic Proper (station Huvudskär Ost), in the Southern Baltic Proper (station Southern Baltic) and in Skagerak (station Väderöarna). Since 1991, wave measurements in the western Baltic Sea have been carried out in the area of Darss Sill (with GKSS Research Centre as the operator), and since 2002 at a station northwest of Cape Arkona, where measurements are made by the Federal Maritime and Hydrographic Agency of Germany (BHS). Long-term climatological wave data are not yet available at the latter position. Up to now, measurement interruptions due to ice formation occurred in the winter of 1995/1996 at the Darss Sill measuring station and in February and March 2010 at both stations. (Pettersson et al. 2011)

As stated before a characteristic feature in the Baltic region is the seasonal variation, with higher wind speeds in wintertime and lower wind speeds in summer. Respectively the mean significant wave height is lower during summer and higher during the winter (Figure 3.). According to Jönsson (2002) the dominant waves are 0.5 m lower and 1 s shorter during summer than in the winter period. As it can be seen in Figure 3 the difference in wave height can be more than 1m between summer and winter months depending on the location.

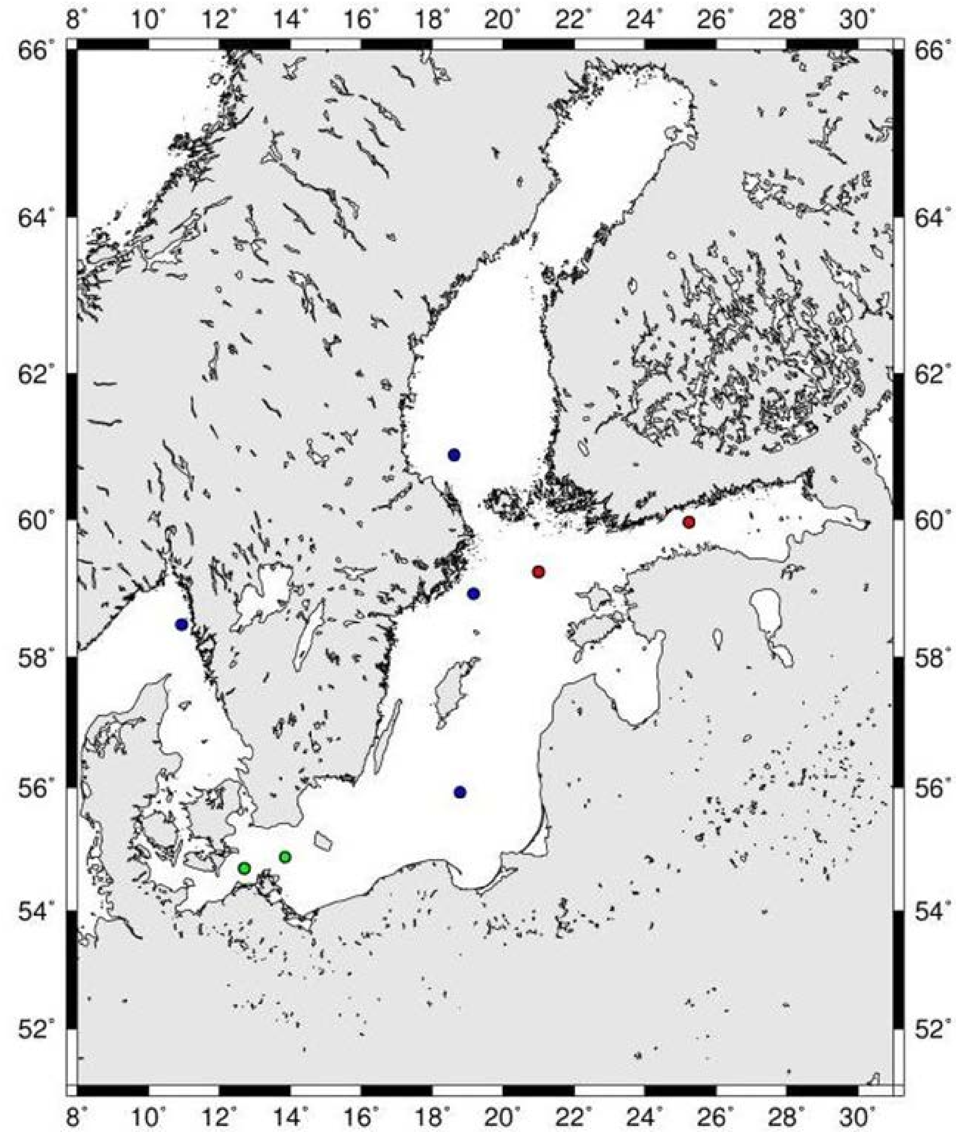

Figure 8. The position of wave measuring sites in 2010. Red dots indicate FMI buoys in the Northern Baltic Proper and in the Gulf of Finland, blue dots SMHI buoys in the Southern Bothnian Sea, in the Northern Baltic Proper, in the Southern Baltic Proper and in Skagerak and green dots the BSH and GKSS buoys off Cape Arkona and on the Darss Sill. (Pettersson et al. 2011)

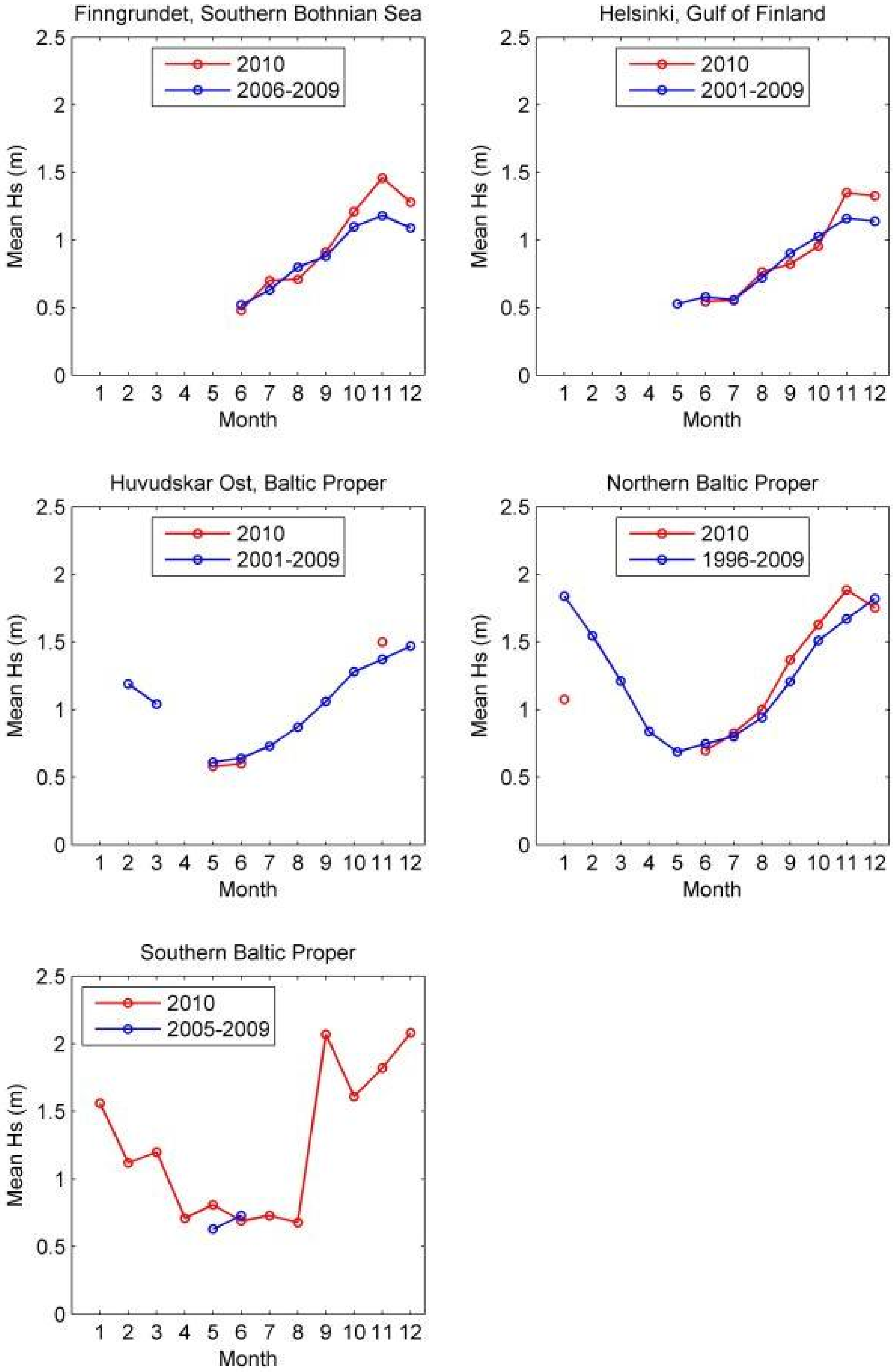

Figure 9. The monthly means of significant wave heights in the Southern Bothnian Sea, the Gulf of Finland and the Baltic Proper. In some months the long-term statistics are calculated over fewer years (but at least over four years) than indicated in the legend. (Pettersson et al. 2011)

The intermittent nature of ocean waves is a problematic area for ocean wave energy capture, especially the extreme power differences experienced in storms compared to average power levels which can have a harmful effect on the survivability of the equipment. When designing a wave energy converter for a certain site, there are many parameters to consider. The design choices may vary a great deal depending on where one chooses to focus, and any decision will be a compromise. The extreme levels of energy flux are a reality in the oceans that all designers of wave energy converters must consider, and with great respect. Although most likely published only in regular media rather than in scientific journals, the harsh conditions of the oceans and the extreme power of ocean waves have wrecked many attempts to wave energy conversion. The wave energy converters must be designed to survive in these conditions. However, since a wave energy converter cannot be designed to have an installed power corresponding to the 100-year wave some compromise is needed in order for the energy converters to be of realistic proportions from an economical perspective. Perhaps the best alternative for a design basis are the combined scatter and energy diagrams, as these contain the most information. In the diagrams it is clearly visible where the energy is located and hence for which energy flux, wave height and period the equipment could be designed for. (Waters & al. 2009.)

4.4. Sea ice

The season to harvest wave energy is shorter, due to ice covering much of the northern part of the Baltic Sea during the winter season. Ice formed from seawater is saline, unlike lake or river water ice. It can be said that about a third of the salinity in the water from which it is formed remains bound in sea ice. Salt and other impurities are located between the ice crystals, and as a result of this, sea ice is weaker than freshwater ice. In the Baltic Sea ice conditions vary greatly. On average, ice covers an area of some 218,000 square kilometres. The annual ice cover is at its greatest between January and March, usually around the end of February or beginning of March. The maximum ice covered area varies between 52 000 and 422 000 square kilometres, which stands for 12-100 per cent of the total Baltic Sea area including Kattegatt and Skagerrak. (Baltic Sea Portal 2012.)

The Bay of Bothnia and the eastern Gulf of Finland gets an ice cover every year. About once every decade only a small area in the southern Baltic Sea remains ice free. The ice formation in the Baltic Sea starts along the coasts of the northern Bay of Bothnia and the inner Gulf of Finland. This occurs usually in October-November. Thereafter the freezing spreads to the Quark, the open Bay of Bothnia and the coasts of Sea of Bothnia. In normal winters the ice gets to cover also the rest of the Sea of Bothnia, the Archipelago Sea, the whole Gulf of Finland and parts of the northern Baltic Proper. In mild winters the Sea of Bothnia doesn’t freeze at all and the Gulf of Finland only gets a partial ice cover. In severe winters the ice reaches the Danish Sounds and the central Baltic Proper. The last area that freezes up is an area north-east of Bornholm in the Southern Baltic Sea. (ibid..)

The melting season starts in April and proceeds from the south to the north. In the northern Baltic Proper the ice disappears in early April. By the beginning of May there is only ice left in the northern Bay of Bothnia, where also the last ice pieces melt away by the beginning of June. On average the ice season in the northern Baltic Proper lasts for less than 20 days. In the northern Bay of Bothnia there is ice for half a year. (ibid..)

The ice in the Baltic Sea exists as fast ice and drift ice. Fast ice is situated in coastal and archipelago areas, where the water depth is less than 15 meters. It develops during early ice season, and remains stationary to the melting period. The drift ice has a dynamic nature being forced by winds and currents. Drift ice can be level, rafted or ridged, and its concentration could be 1-100%. In media, drift ice is occasionally called pack ice. Pack ice is drift ice with concentration more than 80%. The term has no dynamic meaning. (ibid..)

Drift ice movements are large: in stormy conditions thin drift ice field can move 20-30 km in a single day. The motion results in uneven and broken ice field with distinct floes up to several kilometers in diameter, leads, and cracks, slush and brash ice barriers, rafted ice and ridged ice. The ridges and brash ice barriers are the most significant obstructions to navigation in the Baltic Sea. (ibid..)

The Finnish Ice Service of the FIMR (Finnish Institute of Marine Research) classifies the severity of the Baltic Sea ice seasons into five classes: extremely mild, mild, average, severe, and extremely severe. Classification is done according to maximum extent of ice cover in 1720-1996. The maximum ice extent has been calculated for the day when the annual maximum has been reached. In calculations ice concentration, thickness or ice deformation degrees have not been taken in account. The classification is based on the area of the total ice extent. (ibid..)

4.4.1. Ice formation in the experiment site near Åland

The nearest measuring point for ice formation to project experiment site is south of Åland in Kobbaklintar. Those locations are close enough to generalize the phenomenon. Ice in the area will appear from the week on average in five weeks, depending on the distance to the coast. During years as which ice in the area appears: Ice forms typically on the area during the first part of February and will disappear at the end of March (Table 1). Ice has been created at its earliest to the area at the turn of the year (in ice winters 1978-79, 1994-95, 2001-02 and 2002-03) and at latest as late as in the second week of March (in ice winter 1997-98). Ice will disappear at latest from the area at the beginning of the second week of May (in ice winters 1965-66 and 1969-70); at earliest already before middle of January (ice winter 2001-02). There has been 17 totally ice free winters in in the area. (Vainio 2011).

First freezing			Permanent ice cover			End of permanent ice cover			Final disapearance of ice			Number of real ice days		
earliest	median	latest	earliest	median	latest	earliest	median	latest	earliest	median	latest	min	median	max
29.12.	7.2.	9.3.	30.12.	11.2.	17.3.	13.1.	28.3.	29.4.	14.1.	1.4.	7.5.	0	37	111

Table 1. Ice winters in Kobbaklintar south of Åland 1960-61 – 2009-10 (Vainio 2011).

4.5. Seabed topography and geology

Seabed topographic features describe the geomorphological differences and structures of the seafloor. Good data of seabed characteristics is valuable information when planning and implementing offshore projects. Of course on site investigations are always needed. Seabed substrates and the gradient determine also the location of wave energy converter. A point absorber device that is mounted on a concrete foundation needs a flat surface to stand straight, like sand, gravel or clay. The seabed substrate should not be too soft or else it risks the device to sink or tilt. In the Baltic Sea region the seabed geology has not been well known and a one challenge has been that the existing national and international data are very diverse in a multinational region.

In the EU-funded BALANCE project the available data from different institutes around the Baltic Sea was collected. The Baltic Sea sediment map and marine landscape map were produced. The sediment map includes five substrate classes that were possible to translate from existing (national) substrate classification systems (Figure 4.). The researchers revealed also a total of 18 unique seabed topographic features (i.e. marine landscapes) from the Baltic Sea and the Skagerrak (Figure 5.). Plains with both coarse substrates and mud and clay are common throughout Baltic Sea. Coarse substrates plains, in particular, cover large areas. Basins, particularly with mud and clay, are also common. Plains and basins together cover two thirds of the seabed. Mud and clay areas include about one third of the seabed. From these, mud areas represent the areas of actively ongoing sedimentation. Mounds with hard clay and clay are fairly typical throughout the Baltic Sea, but especially in the Skagerrak, the Åland Sea and the Archipelago Sea. Sand mounds are most frequent in the Kattegat, the Sound and the Belt Sea, the Gulf of Riga and in the Bothnian Bay, but still cover less than 1/10 of the seabed in each zone. Humps with complex sediments are characteristic features in the Kvarken area in the northern Baltic Sea. Bedrock mounds are relatively typical in the Åland Sea and Archipelago Sea. Sea troughs are generally rare, but can also be found in the Åland Sea and Archipelago Sea. (Kotilainen & Kaskela 2011.)

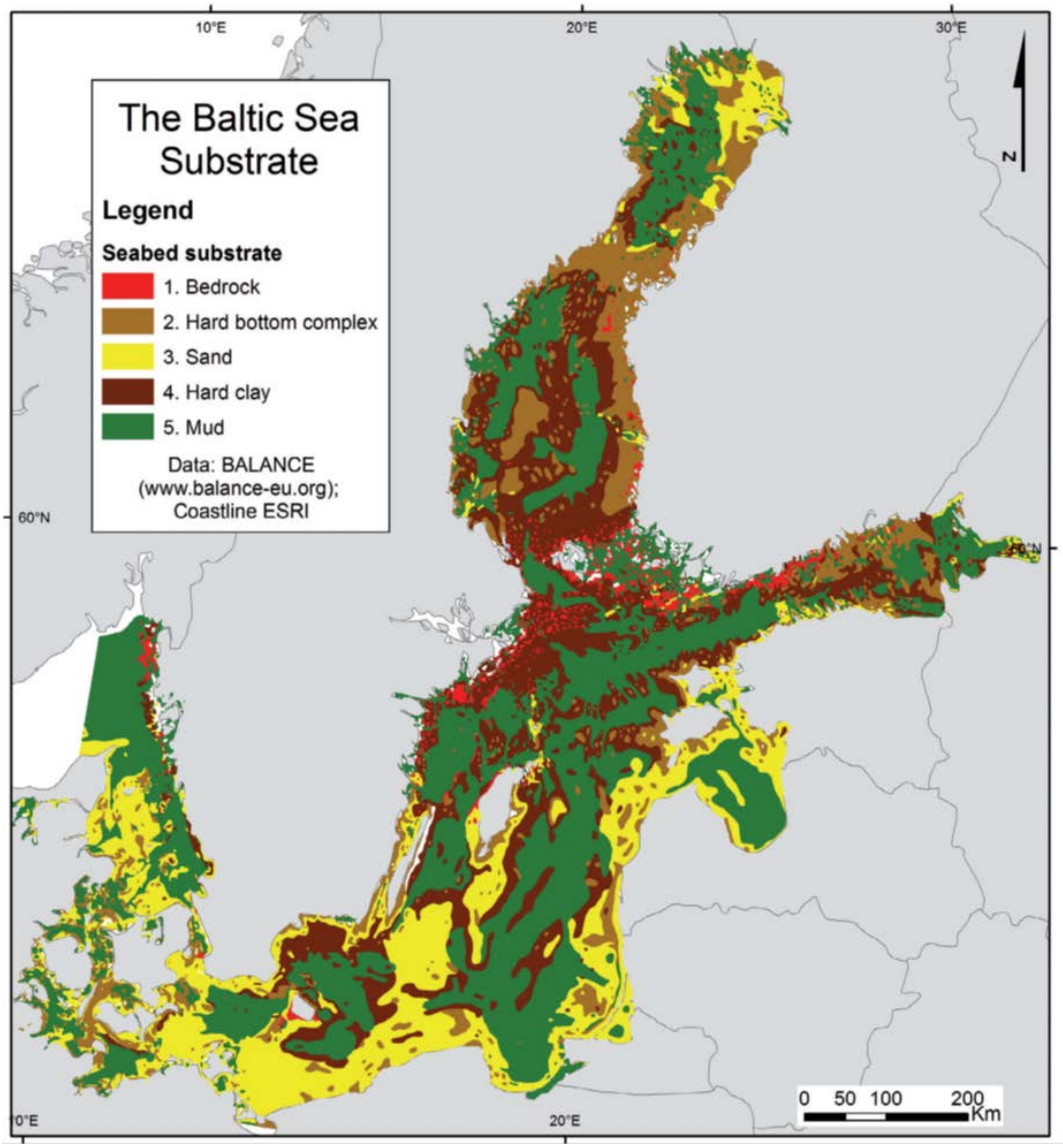

Figure 10. Substrate map of the Baltic Sea seabed (Kotilainen & Kaskela 2011).

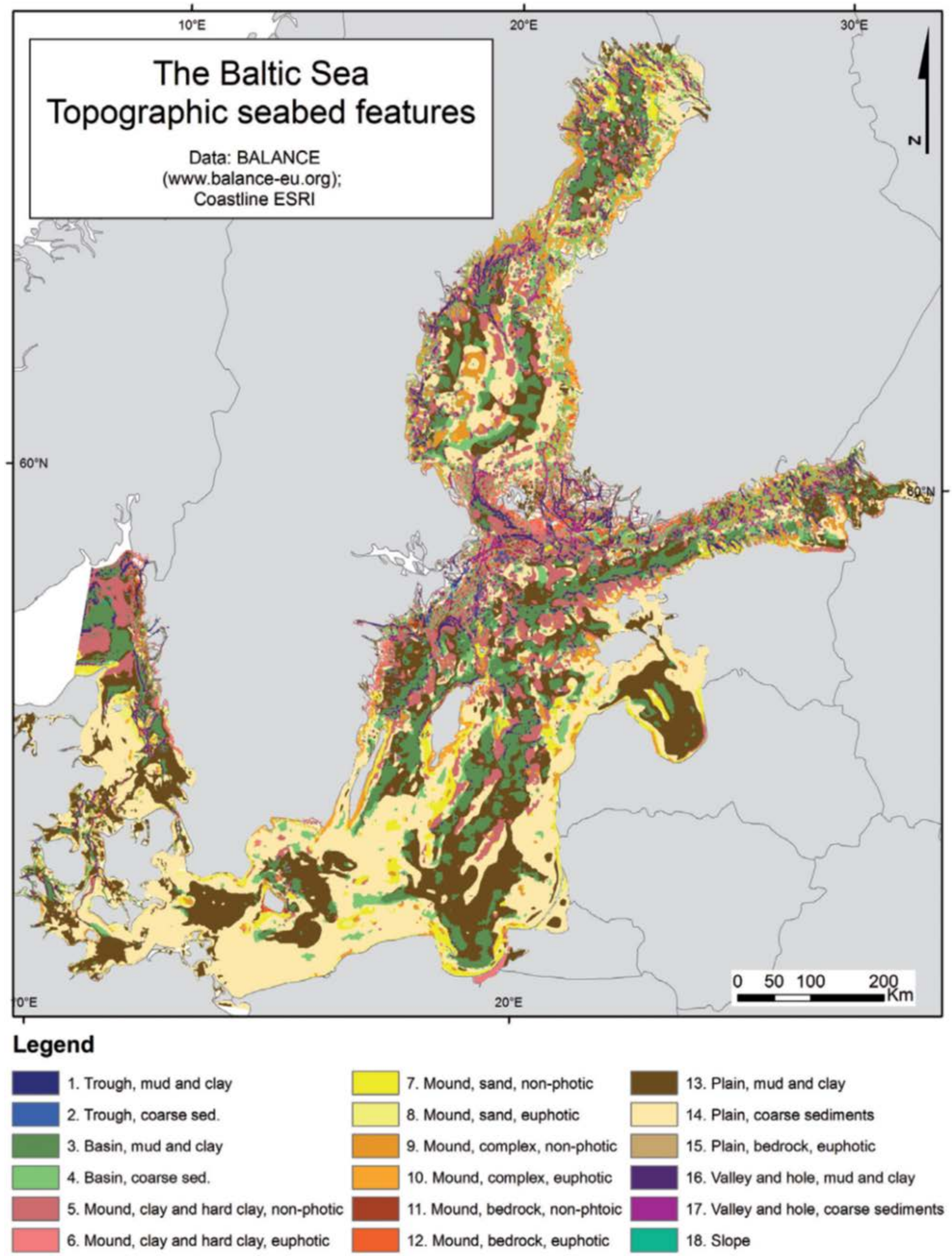

Figure 11. Topographic features of the Baltic Sea (Kotilainen & Kaskela 2011).

5. Possibilities of wave energy in the Baltic Sea

5.1. Energy potential in the Baltic Sea

Various estimations indicate that the world's potential for wave energy is 10000-15000 TWh per year. That is almost the same as the economic potential of hydropower in the world. In the Baltic Sea alone, the potential is calculated to be 24 TWh. The term 'technical wave energy output' takes into account source availability, capture efficiency and losses in the power chain, as well as sociological and ecological limitations for wave power plant deployment. In the power range 20–30 kW/m wave front the global technical resources are estimated to 100–500 TWh/year. For even lower power regions, 10–20 kW/m wave front, these figures are estimated to be doubled. Yet, the possibilities of wave energy in sheltered waters have been poorly investigated. (Bernhoff et al. 2006.)

Henfridsson et al. (2007) calculated in their study that the annual wave energy is 56 TWh for the true Baltic Sea. However, a study by Bernhoff et al. (2006) indicates a smaller potential 24 TWh. The study by Bernhoff et al. can be recognized as a technical potential and it presents a possible scheme for a large-scale rollout, whereas the result from the work of Henfridsson et al. is more to be considered as gross wave energy potential for the whole Baltic Sea. The 24 Twh potential is 33% of the energy generation of Finland in 2009 (table 2.).

However, Heinfridsson et al. states that several societal questions will to some extent decrease areas possible for exploitation, foremost shipping lanes, areas important for fishing and marine protected areas. Other human activities or interests, such as areas of military concern or archaeological sites could limit access to areas, but probably not to such an extent that it would reduce actual potential. Many of these factors are also more costal, which reduces risk of conflict. Numerous areas would likely become restricted for future offshore projects, including wave power. Nevertheless, wave array parks, due to progressive absorption of energy, have to be dispersed and in smaller groups. Suggested inter-distances between buoy-groups in the Baltic are up to 60km. If areas of societal concern would be considered as areas of fetch the true potential of energy absorption could still be close to the theoretical maximum. Same kind arguments could be used for unsuitable seabed substrates and for the few parts of the Baltic Sea being too deep to explore. Therefore, a theoretical maximum utilization may not differ substantially from what could be practically achieved. (Henfridsson et al. 2007.)

5.2. Wave energy technology in the Baltic Sea

There have been many attempts to successfully convert the irregular wave energy into electricity. The dominating idea has been to use one large unit, which can convert a lot of power. Several technical solutions for wave energy converters are possible. However, Bernhoff at al. (2006) assumed that the electricity can be generated in Baltic Sea at a competitive price using a point absorber that drives a generator. The unit size for power production is assumed to 10 kW to match a significant wave height in the range of 2m with reasonable buoy size. One example of such a concept is the point absorber buoy. Another solution is through the use of a linear generator where the moving piston is driven by a point absorbing buoy. Furthermore, Bernhoff at al. assumed that the technology is somewhat depth independent, which would be the case for a buoy anchorage to sea floor at reasonable depth. This kind of version of the moored buoy concept is developed at Uppsala University, and uses a linear electrical generator placed on the ocean floor. This is the same technology that is used in the project WESA and is built by Seabased Ab. A line from the top of the generator is connected to a buoy located at the ocean surface. The buoy is acting as power take off. Springs attached to the translator of the generator store energy during half a wave cycle and simultaneously act as a restoring force in the wave troughs (Falcao 2010).

The season to harvest wave energy is shorter, due to ice covering much of the northern part of the Baltic Sea during the winter season. This has to be taken in to account. There are different approaches to dealing with the icy sea conditions. The ice moves and therefore the wave buoy will have to move in under the ice as it moves by. One approach is to change to design of the wave energy buoy in order for it to passively move in under the ice. Another might be to actively submerge the buoy underneath the ice, during the icy winter season. For both options there are many design alternatives. Surviving the icy conditions are tested during the project WESA. (WESA 2011.)

5.2.1. Energy production in the Baltic Sea

Theoretically, up to 50% of the incoming wave energy can be absorbed by a system of oscillating point absorbers, i.e. an array of buoys. For individual buoys absorption of 20% of the incoming energy has been observed. In a simplified model, buoys at the back of an array will receive less energy than those at the front for a wave field with a predominant direction. To improve this situation, Bernhoff et al. suggest that, the buoys could be arranged in a hexagonal pattern, forming a large circle. They calculated the technical resources for a supposed hexagonal distribution of arrays each containing 379 wave energy converters. The converter consists of a linear generator of average power production of 10kW, driven by a 4m in diameter point absorbing buoy. These dimensions are chosen to match the wave climate of the Baltic Sea, and yield an estimated utility factor of 30%. The useful depth depends very much on selection of technology. For the anchorage buoys most of the Baltic, with depths in the range of 100 m, are considered applicable. Thus, an array of 379 converters in the Baltic Sea is expected to generate 10GWh in one year. (Bernhoff et al. 2006.)

The Seabased Ab has calculated that installed power of a medium large wave energy park with 2000 generators, with an average power of 10 kW per generator, is 20 MW with an expected annual production of 50 GWh. This kind of wave energy park would satisfy the energy need of 2500 houses, if the yearly energy consumption of detached house (in Finland) is in average 20 000 kWh. Compared to yearly energy production of Baltic Sea countries (Table 2.) for example Latvia would need 112 medium large wave energy parks to replace the country's hole energy production. In case they would change the energy production totally to renewable energy sources, they would need only 40 wave energy parks to replace all the fossil fuels. However, the calculated energy potential of Baltic Sea 24 Twh (Bernhoff et al. 2006) is much larger. That would be enough for smaller Baltic Sea countries to satisfy their energy need, but obviously wave energy should be used in all coastal areas and in the archipelago. Local energy production in the archipelago and coastal areas would give them also energy security.

Country	Gross electricity generation	Share of renewables
Sweden	136,72 Twh	58 %
Finland	72,06 Twh	30 %
Estonia	8,78 Twh	6 %
Latvia	5,57 Twh	64 %
Lithuania	15,36 Twh	4 %
Poland	151,72 Twh	6 %
Germany	592,42 Twh	16 %
Denmark	36,36 Twh	28 %

Table 2. Gross electricity generation in Baltic Sea countries in 2009 (Europe's Energy Portal 2012).

The ice situation during winter season is of course limiting the energy production. Although many parts of Baltic Sea are ice free hole year. Only the Northern parts and inner bays gets ice cover every year. The tendency of milder winters has also reduced the extent of the ice cover during past decades. In the areas of good fetch and bigger waves the ice formation is not so fast. Arguably the best places for wave energy production are not so easily disturbed by ice formation.

5.3. Investment costs

Several factors clearly affect initial investment costs and thus the potential for development at certain sites. One important thing is distances from land: the further the distances the larger costs during construction. The wave array park size will also affect the costs. Distance will affects cable costs; normally a large part of the total cost for offshore projects, and this in turn will affect optimal park size. In this case we have to more carefully considered system losses, yet another factor to consider. The electric transmission system losses are estimated and cannot be regarded as exact values. In the overall system, from wave to wire, several loss parameters has been identified, some of which are related to the electric transmission. It should be noted that the transmission efficiency of 90–95% is comparable with the generator efficiency. The best option would be to install a fairly large farm close to the grid. Detailed economical analysis is required prior to any real installation plans, as several parameters are unknown today (e.g. installation costs, local power company loss evaluation). The choice of placing transformers offshore also requires considerations, as the optimization is a multivalent problem. Some parameters that should be taken into account are transmission distance, cable installation cost, and cost of copper, site depth and electricity price. (Henfridsson et al. 2007.)

Investments in renewable energy plants normally only take standard economic key figures into account, such as installed rated power, the market price of energy and the interest rate, when considering the economic aspects. Leijon et al. (2003) propose that the degree of utilisation, i.e. the ratio of yearly produced energy in the installation to the installed power, must be included due to its significant impact on the present value of the investment. A site with a limited average wave height could be of economic interest if the utility factor for the installation is high, since the investment cost (associated with the power installed) can be better adjusted to conditions at the particular site. In the case of wave power from the Baltic Sea with its limited variation in wave height (and limited average wave height), this indicates that the economic potential is best for smaller units.

As a conclusion of the ideas of Henfridsson et al. and Leijon et al. the optimal investment costs in the Baltic Sea region are achieved when building smaller units close to the grid.

5.4. Requirements and restrictions for location

Locating commercial wave array parks may become restricted by a number of interactions, including on-going human activities and physical conditions, thus reducing the theoretical gross potential. Such activities include shipping lanes, commercial fishing, areas of military interest, sites of marine archaeological importance and valuable biological areas, including marine reserves. Geophysical conditions further set boundaries of what are economically feasible, such as distances from land and grid, and the depths and substrate of the seabed. With devices placed at the seabed, the seafloor conditions and local geology will affect the possibilities of placing generator units at specific sites or influence employed technique, while conditions at sea level are less complex. (Henfridsson et al. 2007.)

5.4.1. Human activities

Military areas and shipping lanes should obviously be avoided and archaeological sites near shore are usually commonly known. Leisure boats are unlikely to be affected as much as these commonly occur near shore. Yet, collision risk assessment will be required. Wave energy park need to be marked clearly also with lights, so that the buoys are visible also at nighttime. Final considerations also have to include existing cables, pipelines and dredge sites. For any offshore projects, on site investigations using multi-beam sonar will be required, both from project perspective and for obtaining necessary permits. Such surveys will also give extra seabed information including archaeological findings, wrecks, post war dumpsites, etc. (Henfridsson et al. 2007.)

Commercial fishing and areas with high biodiversity, including present and planned marine reserves, are subjects of larger concern. It is unlikely that buoy arrays would be allowed into areas with high biological values. This is anyway unlikely to happen with point absorbers, if generators will be placed in areas of depths ca. 30 m, which can be considered a crucial biological depth in the Baltic and other temperate seas. However, the gravity foundations of linear generators in a wave array park will take quite a lot space in seafloor and during the deployment phase some organisms may be buried and suppressed. That will obviously have some effects locally. Thus, shallower marine banks, were biodiversity is high, will not come in question for point absorbers. (Henfridsson et al. 2007.)

Areas of concern for commercial fishing may become an issue and will have to be dealt with from case to case. As in several offshore wind projects, compensatory fees may have to be paid for loss of fishing waters. Consequently, marine life may to some extent be affected also from wave power installations, particularly if they are areas demanding, but not necessarily and not only negatively. Marine organisms will be attracted to equipment, an effect caused by biofouling and attraction by so-called "artificial reefs" and "FAD" fish attracting devices. Moreover, buoy array parks will hinder fishing, which in fact may help protecting areas, and even populations or species. Buoy array parks could thus function as marine reserves. Finally, it has been proposed that point absorbers and other wave power techniques may in fact reduce coastal erosion, although this require near shore installations and windward coasts. (Henfridsson et al. 2007.)

5.4.2. Seabed suitability

A point absorber could be mounted on for example a concrete foundation, which requires flat seabed, commonly clay, mud or sand. On hard substrates different drilling techniques could be employed where generators would be mounted on an axis attached into the rock, but hard substrates commonly are more undulating, which requires further considerations. (Henfridsson et al 2007.)

In the true Baltic area roughly 23% of the seabed is covered by harder glacial clay and 39% of softer postglacial mud/clay. The latter substrates are mostly found in deeper areas and centrally in the sea. Postglacial sand covers 27% of the seabed and is mostly found at southern and eastern Baltic coasts, along with shallower banks. Only 11% consists of harder bedrock or moraine. (Henfridsson et al. 2007.) The best substrates for point absorber with concrete foundations are sand, gravel or harder glacial clay.

Before deploying wave energy converter on site investigations will be required. The seabed geology and topography in the Baltic Sea has a great variance (Figures 4. and 5.). If the site is not checked beforehand there can be a danger for equipment. Too soft substrate can make it sink or tilt and the result is malfunction or broken equipment.

5.5. Climate change effects

The global processes have their effects also in the Baltic Sea region and that has also effects on wave energy production in the region. Climate change in the Baltic Sea basin is related to overall global climate change, and projections of future climate change in the Baltic area build on global and regional climate models and emissions scenarios for greenhouse gases and aerosols. The climate of the Baltic Sea basin is characterized by large seasonal contrasts, owing to its geographical location, variable topography, and land-sea contrasts. The climate is influenced by major air pressure systems, particularly the North Atlantic Oscillation during wintertime, which affects the atmospheric circulation and precipitation in the Baltic Sea basin. (HELCOM 2007.)

In the Baltic Sea, there has also been a general tendency toward milder sea-ice conditions during the past century; this is reflected in time series data on the maximum annual extent of sea ice and the length of the ice season in the Baltic Sea. The largest change has been in the length of the ice season, which has decreased by 14–44 days over the past century, mainly due to earlier ice break-up. On the basis of the ice extent, the shift towards a warmer climate took place in the latter half of the 19th century. During the past ten years, all ice winters have been average, mild, or extremely mild. (ibid..)

The mean sea surface temperature of the Baltic Sea is projected to increase, resulting in a marked decrease in the extent of ice in the sea. The projected decrease of ice cover by the end of the 21st century is dramatic, with the Bothnian Sea, large areas of the Gulf of Finland and the Gulf of Riga, and the outer parts of the southwestern archipelago of Finland becoming, on average, ice free. The length of the ice season would decrease by 1–2 months in the northern parts of the Baltic Sea and by 2–3 months in the central parts. (ibid..)

This change toward milder sea-ice conditions will benefit the wave energy production in the Baltic Sea. Ice cover prevents the energy production during winter, but if there are more totally ice free areas and the ice season in general is shorter there are more opportunities to produce energy. Consequently more locations can be used for wave energy production and there are more locations that are ice free all the winter. Winds and also waves are stronger during winter time with the result that the energy production will be better. This also indicates that the wave power have better potential in the Baltic Sea area. However, there are also new climate scenarios that indicate colder winters in Baltic Sea, but the general tendency toward milder sea-ice conditions has been seen during the past century.

5.6. Comparing wind and wave power

The wind and wave energy are both renewable energy sources. The wind energy is already in the market and widely known. Wind energy is generally considered to be about twenty years ahead of wave energy in its state of development. The slow development of wave energy has many reasons. The high costs of constructing, deploying, maintaining and testing large prototypes under sometimes very harsh environmental conditions, has hindered the development of wave energy systems; in most cases such operations were possible only with substantial financial support from governments (Falcao 2010).

Compared with e.g. wind and solar power the waves have a higher energy density and more predictable occurrence. Wave energy can be considered as concentrated form of solar energy and generated by wind. The wind speed, duration and the fetch are the aspects affecting the forming of the waves. In this way, the original solar power levels of typically ~ 100 W/m^2 can be transformed into waves with power levels of over 1,000 kW per metre of wave crest length (WEC 2010). Waves will continue to travel in the direction of their formation even after the wind dies down.

Most renewable energy sources have naturally variability. This variability has been a problem for developers, because energy retailers require constant or predictable energy production. Otherwise lots of reserve capacity in the electricity grid is needed. Wind energy has been criticized much for its supposed high level of variability. Wave energy will come across this same criticism, but it has better predictability than wind energy and that will reduce the need for reserve capacity. Denniss (2005) compared the variability of wind and wave energy in his study. He constructed a framework which demonstrates that wave energy is, in fact, substantially less variable than wind energy. The functional relationship between wind power and the cube of the wind speed contrasts somewhat with the corresponding relationship between wave power and the square of wave height. Dennis states that lower variability of wave power can be considered a major advantage in terms of providing a more reliable source of energy, but also because it allows the generator used in any wave energy technology to be more precisely rated, resulting in a higher degree of electrical efficiency. This has major implications for the often discussed concept of capacity factor, which is, therefore, implicitly much higher for wave energy

5.7. EU strategy for the Baltic Sea region

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 also 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. It has benefits in climate change mitigation, because wave energy helps reducing emissions. It also improves energy security in local areas and can have effects on energy markets. It may also affect priority areas of entrepreneurship as well as research and innovation. The wave energy is green energy and it has very little environmental effects.

6. Conclusions

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 geophysical conditions. However most likely these wave energy parks would be disperse and suited with the environment.

The wave energy production is suitable for local energy production in archipelago and coastal areas. It is renewable, green energy and with this technology the maintenance should be rather easy. It could be also a solution for energy security in archipelago.

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