YRKESHÖGSKOLAN NOVIA

Construction of offshore wind farms in Finland

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Abstract

As the popularity of oil industry is decreasing and people are investing in finding sustainable solutions, the interest in renewable energy has been increasing. Especially the amount of offshore wind farms has been growing a lot during the past years.

This is a study about how the offshore wind farms are constructed in Finland and what kinds of challenges are faced during the construction. This study is based on information from articles, project descriptions and interviews with offshore wind energy professionals.

The thesis consists of four areas: general information of offshore wind farms and their substructures, the descriptions of construction processes of two existing offshore wind farms in Finland, the challenges and conclusions.

Language: English Key words: offshore, wind farm construction, renewable energy

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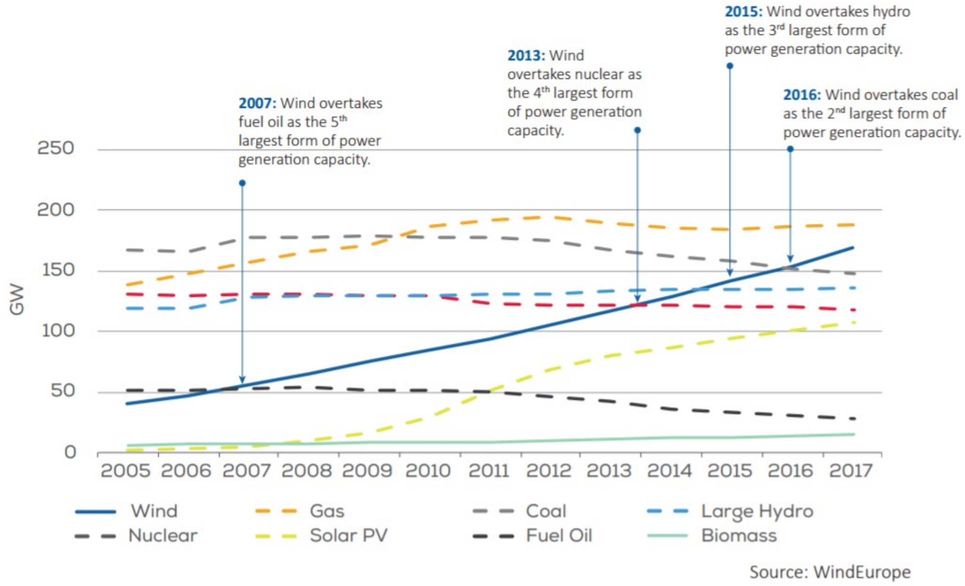
1 Introduction

The investments to sustainable energy solutions, such as to wind power, are growing (Picture 1). Due to stronger and more continuous winds at sea, offshore wind farms can produce more energy than the ones onshore. Almost all the current European offshore wind farms are located on the southern parts of the Baltic Sea and on the North Sea due to more suitable climate, but today wind farms designed for icy conditions have also been developed.

We made a research during our exchange studies in the Netherlands for a local offshore company in spring 2017. It mainly focused on offshore wind power in the North Sea, but the situation in Finland was used as a comparison. During our research we found out, that Finland is not investing as much to the offshore wind power compared to many European countries; there are currently only two offshore wind farms ready and in operation. For this reason, we decided to research how the offshore wind farms are constructed in Finland, what are the possible challenges and how they are faced.



Picture 1: Power generation capacity in the European Union 2005-2017 (WindEurope, 2018).

1.1 Aim of the thesis

Since the climate in the Baltic Sea is very different compared to many European countries, our aim in this thesis is to describe how the offshore wind farms are constructed in Finland

and what kind of special techniques and solutions are used in the construction. We will also be researching the challenges the climate brings to the construction and how these challenges are met.

1.2 Research questions

The main objective of this thesis is to find out the challenges in the construction of offshore wind farms in Finland. In order to reach this goal, we have a number of sub-questions, which are listed below.

- How are offshore wind farms constructed in Finland?
- What kind of challenges does the Finnish climate bring to the construction of offshore wind farms? What kinds of other challenges are met during the construction?
- What kind of solutions and special techniques are used in the construction of offshore wind farms?

1.3 Research methods

In this thesis, we are using qualitative research method. Our aim is to gather information from articles related to the offshore wind farm projects in Finland to find out the special techniques used in the projects. We will also interview a company, who has been leading the first offshore wind farm project designed for icy conditions. Our main interest is to find out the biggest challenges in the construction, how these challenges were faced and what has been the role of maritime professionals in the field.

1.4 Limitations

This thesis will only focus in the situation in Finland; already existing wind farms, the current situation and future plans. Leading countries in offshore wind energy will be used as a comparison and comparison between Nordic countries will be made as well. Also a comparison between the substructures used in Finland, the rest of the Baltic Sea and North Sea will be made. The thesis will only focus on the construction of the wind farms. The challenges in the maintenance are not covered, since the amount of data available is not sufficient yet.

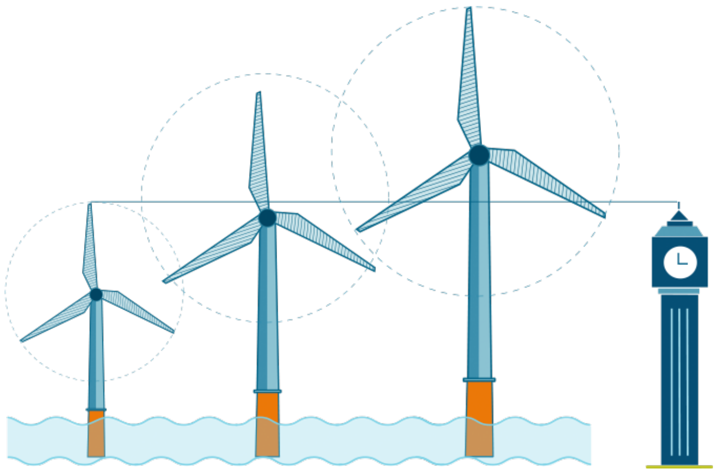
2 Wind farms

Wind farms are areas, where multiple wind turbines are located on the same place with a purpose to produce electric power, generated from wind. Wind energy is becoming more and more attractive, while energy prices are getting higher and interest in renewable resources is increasing. Especially many of the European countries want to get rid of the nuclear, oil and gas energy production and rather invest in renewable energy resources, such as wind energy.

The first-generation windmills were designed to pump water or grind grains for farmers. Nowadays windmills have evolved to wind turbines, which produce electricity and are connected to an electricity grid or a single home or building. Basically, all wind turbines function in the same way. When the wind blows, air hits the foil-shaped blades, which start to turn. The pitch of the blades can be adjusted to control the rotor speed, in case the winds are too high or low to produce electricity. Usually wind turbines are made of two or three blades. The blades are connected to a shaft with a gearbox, which turns a generator producing electricity. There is also a brake, yaw drive and yaw motor for turning the turbine in the direction, which is optimal for the wind. The turbine tower gives the ground support and optimal height for the wind turbine. For minimizing the service expenses, some offshore turbines can have automated greasing systems to lubricate bearings and blades, as well as heating and cooling systems to maintain the correct temperature on the gear oil. (Management, n.d.).

3 Offshore wind farms

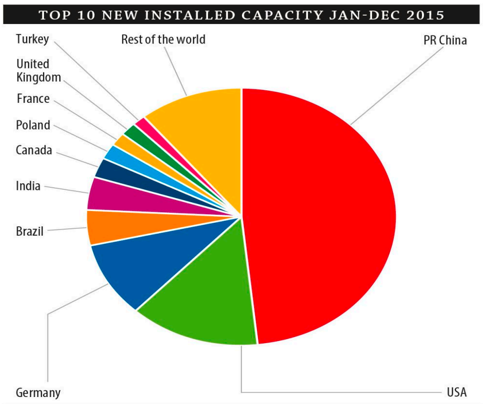
Wind farms are usually located on land, but offshore wind farms have increased in numbers remarkably from the beginning of 20th century. The first offshore wind project began in Denmark 1991 and had an important role for the future offshore wind farms. There are stronger and more continuous winds at sea and therefore offshore wind farms can produce more electricity compared to onshore wind farms. The higher production rates make offshore wind farms more attractive. Offshore wind farms are built more and more in deeper waters, further away from the shore and in bigger farms. Even the turbine sizes are growing all the time (Picture 2). There is a huge potential in the offshore wind energy production. While the production is becoming more efficient and cost competitive, also the turbine technology is developing all the time. On the other hand, offshore wind farms are more expensive to build and maintain than onshore, because they are out at sea. The turbines are exposed to harsh weather conditions and erosion. In too high wind speeds the turbines even tend to shut down. Several different types of vessels are needed to build wind farms and when they are ready, they need maintenance and regular inspections. (Association, 2011).



Picture 2: Turbine size development (Siemens, 2018).

3.1 Offshore wind energy production

Offshore wind turbines can produce up to 40% more energy than onshore wind turbines, because of the higher and more continuous wind speeds. In the end of 2017, there were 92 offshore wind farms in Europe, consisting of over 4000 turbines capable of producing 15 780 MW of energy. The rest of the world is also catching up. Especially China (Picture 3) has increased their investments to the offshore wind energy in order to satisfy the growing need of energy in the country. (Siemens, 2017).



Country	MW	% Share
PR China	30,753	48.5
USA	8,598	13.5
Germany	6,013	9.5
Brazil	2,754	4.3
India	2,623	4.1
Canada	1,506	2.4
Poland	1,266	2.0
France	1,073	1.7
United Kingdom	975	1.5
Turkey	956	1.5
Rest of the world	6,950	11.0
Total TOP 10	**56,517**	**89**
World Total	**63,467**	**100**

Source: GWEC

Picture 3: Wind farm capacity in 2015 (gwec, 2015).

3.2 Offshore wind energy in Europe

The North Sea is particularly optimal for offshore wind energy, because of its all-year-round windy climate. For this reason Europe is still the world's biggest investor in offshore wind energy. At the moment, more than 91% of all offshore wind energy is installed on European waters, but recently also countries outside of Europe have started to show their interest. (GWEC, 2017).

The first European wind farm was set up on a Greek island of Kythnos in 1982. Following the first onshore wind farm, the first offshore wind farm was built in Vindeby, Denmark in 1991. The wind farm consisted of eleven 450kW turbines. Four years later, in 1995, Europe's total wind capacity was taking over the US. Ever since, Europe has dominated the world in wind power.

In 2000, the first large-scale offshore wind farm was constructed in Middelgrunden, Copenhagen. The wind farm consists of 20 turbines, each with a power of 1,5MW. (offshore, 2018).

Another remarkable step in European wind power was in 2009, when the world's first floating wind farm, Hywind, was constructed outside of Scotland. The wind farm consists of 5 turbines, each with a power of 6MW. The water depth in the area, where the floating turbines are located, is 95-120 meters. (Offshore, 2018).

Today Europe invests in wind energy more than ever; the amount of offshore wind farms is growing each year, when new turbines are installed. UK has been the leading country together with Germany and these two countries still have the largest number of turbines connected (Picture 4). (WindEurope, 2017).

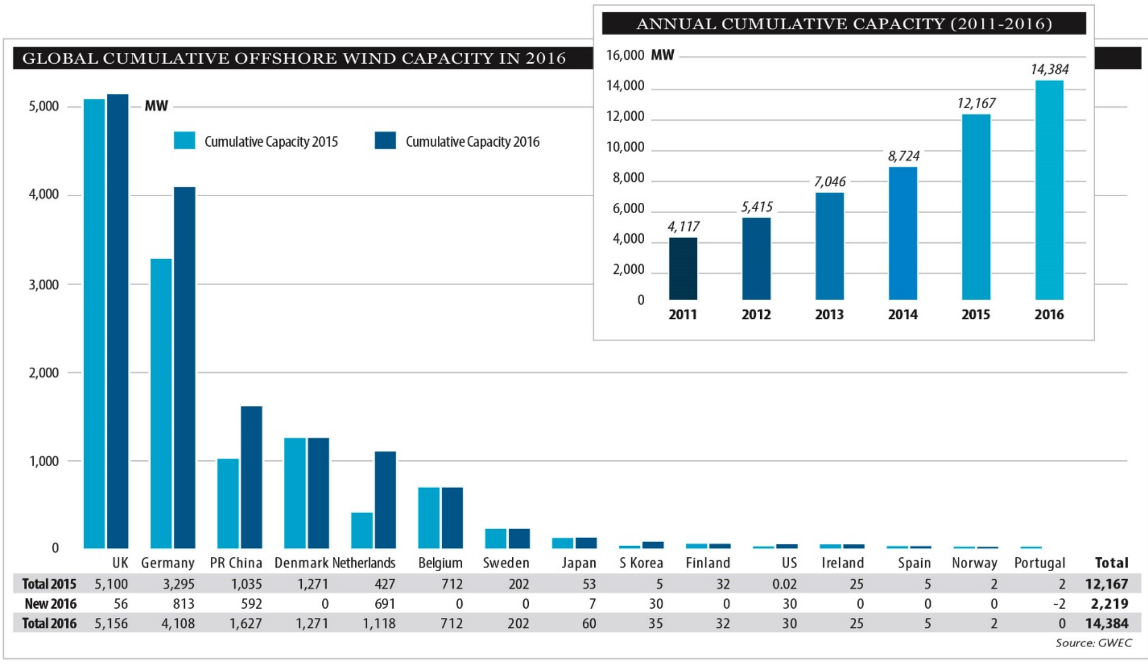
COUNTRY	NO. OF FARMS	NO. OF TURBINES CONNECTED	CAPACITY INSTALLED (MW)	CAPACITY INSTALLED/ DECOMMISSIONED IN 2017 (MW)
UK	31	1,753	6,835	1,679
GERMANY	23	1,169	5,355	1,247
DENMARK	12	506	1,266	-5
NETHERLANDS	7	365	1,118	0
BELGIUM	6	232	877	165
SWEDEN	5	86	202	0
FINLAND	3	28	92	60
IRELAND	2	7	25	0
SPAIN	1	1	5	0
NORWAY	1	1	2	0
FRANCE	1	1	2	2
Total	**92**	**4,149**	**15,780**	**3,148**

Source: WindEurope

Picture 4: Geographic breakdown of Europes offshore wind power in 2017 (WindEurope, 2017).

3.3 Offshore wind energy in the Baltic Sea

Almost all of the current offshore wind farms are located in the southern parts of the Baltic Sea. Denmark has some of the best wind conditions in the world and has also been a pioneer in the development of wind power technology. Denmark also has a lot of companies involved in the wind power business, with production and knowledge covering every aspect of the supply chain (Denmark, 2015). Together with Denmark, Sweden and Germany are also big offshore wind energy producers in the Baltic Sea, but also worldwide (Picture 5).



Picture 5: Global offshore wind power production in 2016 (gwec, 2016).

One of the reasons most of the offshore wind farms are located in the southern parts of the Baltic Sea is the cold climate, which causes challenges to the construction and function of offshore wind farms in the northern parts of the Baltic Sea. There is still very little knowledge on how to manufacture optimal foundations and turbines for icy conditions. However, it is estimated, that the construction of offshore wind farms all over the Baltic Sea will increase drastically during the next decade. There are already several new projects planned in almost all the countries by the Baltic Sea. (4coffshore, 2018).

Baltic Sea does not have as high and constant wind speeds as for example North Sea, but otherwise the conditions are easier, excluding the ice. Maintenance and construction vessels are not as dependent on the weather as in the North Sea. There is a good industrial infrastructure with ports, shallow waters and relatively steady windy conditions. Offshore wind farms can be built in good locations near the coastline, when the cabling costs can be reduced. (Ltd, 2016).

3.4 Offshore wind energy in Finland

In many countries, offshore wind power has reached a significant role in energy production during the recent years and investments to offshore wind energy have increased. But compared to many other European countries, the development of offshore wind energy has been much slower in Finland. (Tuulivoimayhdistys, 2018).

The first offshore wind farm was built in Finland in Tahkoluoto, Pori and has been in operation since August 2017. It is also the first offshore wind farm in the world designed to ice conditions. The wind farm consists of 10 turbines, with a 4,2 GW capacity each. (Hyötytuuli, 2018). Also, a wind farm was constructed offshore in Ajos, Kemi, already in 2006, but the foundations are built on artificial islands (Terramare, 2018).

At the moment, there are no offshore wind farm projects under construction in Finland. However, there are currently altogether 5 offshore wind farm projects underway in different phases of the planning process. Finnish wind power company Rajakiiri Oy is planning two offshore wind projects: one in Röyttä, Tornio and another one in Maanahkiainen, Raahe. The spatial planning for the areas has been approved (SuomenTuulivoimahydistys, 2017). According to the initial plan, the wind farm in Raahe will consist of 70 turbines, each with the power of 3-5 MW (Rajakiiri, 2018).

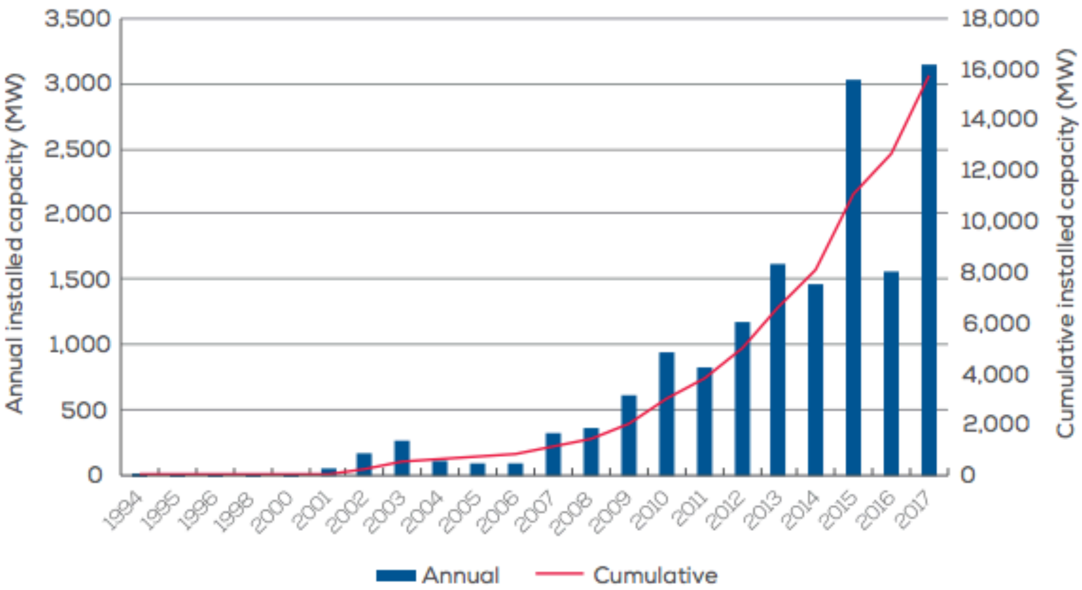
Another Finnish offshore wind power company, Suomen Merituuli Oy, is planning two offshore wind farms: one to Inkoo-Raasepori waters, in the Gulf of Finland and the other to West coast of Finland, to Siipyy, Kristiinankaupunki. Inkoo- Raasepori wind farm will consist of 60 wind turbines of 100 meters in height and each with the power of 3-5 MW. The offshore wind farm in Siipyy will consist of 80 similar wind turbines. Both wind farms will be located 7-8 kilometres from the coast. (Suomenmerituuli, 2017).

WPD has planned an offshore wind farm to Suurhiekka, Ii. The wind farm will consist of 80 wind turbines, each with the power of 5 MW. The project is in its last phase before the actual construction may begin. (Finland, 2018).

3.5 Future of offshore wind power

Wind energy already meets 11% of the power requirements in some EU countries including Denmark, Spain, Germany and United Kingdom (EWEA, 2016). During 2017, Europe installed 16,8 GW of wind power capacity, 15,7 GW in EU. Of the new installed capacity 3,15 MW was located offshore. This means, that the installations in offshore wind power doubled in comparison to 2016. (WindEurope, 2017). The European Union Roadmap 2007 for renewable energy sources has estimated that by 2020, wind energy could provide 13% of the energy consumed in EU. About a third of this energy consumption could be produced offshore. (planete-energies, 2015).

The amount of offshore wind farms has been growing a lot during the past years (Picture 6). Before 2011, offshore wind energy installations in Europe covered only 5-10 % of the whole newly installed capacity. However, during 2015, already about a third of the installed wind energy capacity were installed offshore. When the offshore industry is just getting started in US and Asia, Europe seems to be way ahead. Today a total amount of 15,780 MW of offshore wind capacity has been in installed in Europe, corresponding to 4149 grid-connected wind turbines. (WindEurope, 2017).



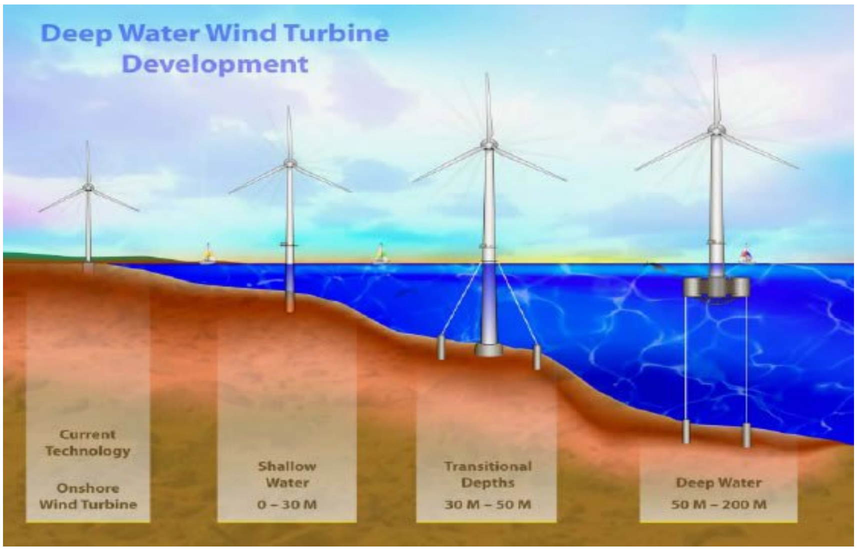
Picture 6: Cumulative and annual offshore wind energy installation (WindEurope, 2017).

There are many reasons, which have been driving Europe towards the increasing use of renewables and especially offshore wind energy. One of the reasons is the new regulations concerning the emissions, such as CO2 reduction. Also, wind energy is not only environmental friendly way of producing energy, but has also become one of the cheapest ways too. The advanced technology in the production of wind turbines, increase in the size of turbines and generators and therefore the increase of the efficiency has been the main reason for the decrease in costs.

Even though there have been some concerns about environmental matters, such as the trouble offshore wind farms could do to marine life, this has not been limiting the amount of newly built offshore wind farms. So, the possible harm caused to marine environment is not the one stopping the offshore wind industry from growing, but it is rather the political issues that are. Even though there have been agreements to achieve all energy from renewable sources by 2030, European political leaders have not been coming up with a proper plan on how to achieve this goal. (Schwägerl, 2015).

4 Substructures

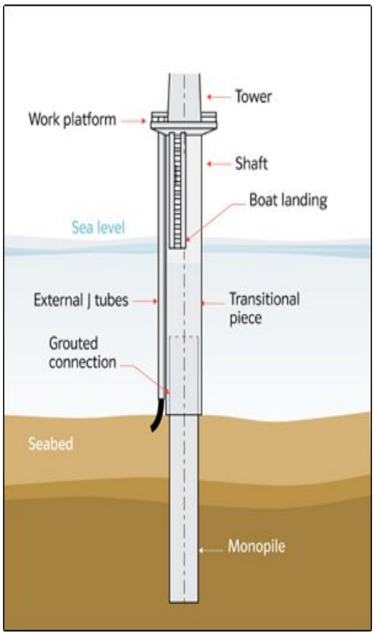
In order to construct offshore windmills, some kind of foundation is needed for the turbine tower and turbine. Different types are used depending on the soil type, water depth, weather conditions, costs, turbine characteristics and maintenance aspects. The offshore support structures can be divided in floating and grounded designs (Picture 7). The main differences in offshore and onshore wind farms are the costs and engineering for substructures. (Association, 2011).



Picture 7: Offshore foundations (Offshorewind, 2017).

4.1 Monopiles

Monopiles are the most common type of substructure. They are simple, cheap and do not require a lot of work to install. Monopiles consist of a steel pile, which is embedded to the seabed. The penetration is adjustable, depending on the environment and seabed conditions. The diameter and thickness of the wall depend on the water depth and turbine size. A transitional piece (Picture 8) is usually used on top of the monopile to connect the turbine tower. Monopiles are usually used in water depths less than 25 meters. In deeper waters, they become too unstable and start to vibrate and bend. However, in the future it is possible to see monopiles with larger diameters, which are less flexible and thus usable in deeper waters. Using jack-up vessels is the most common way to install monopile structures. (4Coffshore, 2013).



Picture 8: Monopile structure (4COffshore, 2017).

4.2 Gravity-based structures

Gravity-based structures are usually used in waters that are shallower than 30 meters. These kinds of structures have been mainly used in the Baltic Sea, because of the shallow waters and calm weather conditions. The structure consists of a gravity weight on the sea bottom, which works as the base for the turbine tower. The foundation is usually made of concrete and has a cylindrical or conic form. The structure is constructed on land and transported to the site. When the structure is laid down on the prepared flat seabed sand, rock, concrete or iron ore is pumped in to increase the weight. The structure often requires some kind of scour protection. The size and weight of the foundation depend on the turbine capacity, water depth and wave conditions. The impact on the nature is often small and the ballast material is usually quite cost-effective solution, especially if the material can be found somewhere nearby the wind farm. (4Coffshore, 2013).

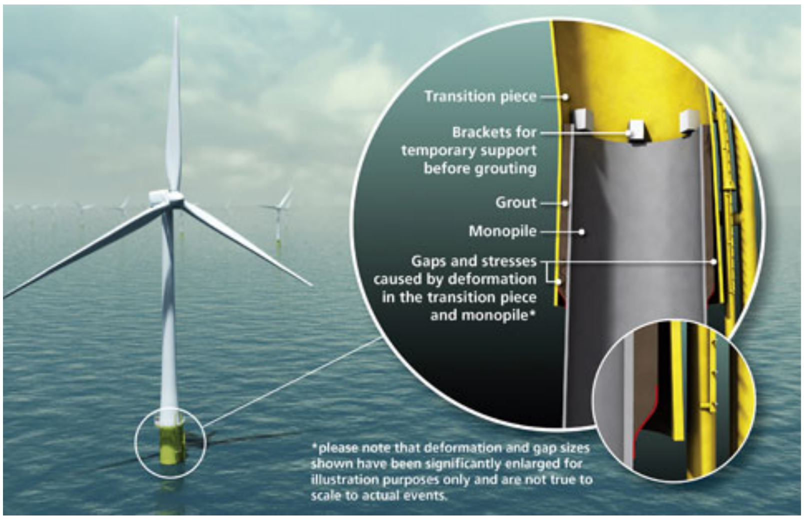
4.3 Space frame structures

Space frame structures are suitable for deeper locations, where for example monopiles or gravity-based structures cannot be used. The space frame structures include tri-pods, tripiles and jackets. These structures consist of several piles, which are fastened to the sea bottom. The structures are pre-assembled at shore and transported to the location with a suitable vessel, where they are lowered to the sea bottom and fastened. Sometimes a mud mat is used to increase the stability. (4Coffshore, 2013).

4.4 Tripods and Tripiles

Tripods are steel structures made of cylindrical steel tubes. They stand up with three legs, which are penetrated to the seabed. The turbine tower is connected to the central steel shaft. The base width and pile penetration can be adjusted, depending on the environmental conditions and the seabed. The piles are driven in to the seabed. Sometimes even suction caissons are used. The advantages of tripods are light weight and stiffness. The tripods also withstand erosion well and the scour effect is not as large as for example with the monopiles. However tripods cannot be used at locations, where the seabed is very uneven and where the water depth is below 7 meters, because the structure can cause problems for a vessel doing inspections and maintenance, because of the draft. (4Coffshore, 2013).

Tripiles are similar to tripods, but the connection between the cylindrical steel legs and the turbine tower is above the sea level. The pile penetration and base width can be adjusted depending on the environmental condition at the site. The tripod consists of three relatively small monopiles for foundation and transition piece. The piles are rammed into the seabed with a special guiding frame. The pile and transition piece are connected with a special grout connection (Picture 9). In the middle of the transition piece is the connection for the turbine tower. The tripile is quite stiff and stable, but might be heavy because of the amount of metal used. It is used in water depths from 25 to 40 meters. (4Coffshore, 2013).



Picture 9: Traditional grout connection (Csmres, 2017).

4.5 Jackets

There are several types of jacket structures. They often consist of three or four legs, which are fastened to the sea bottom with piles. The transition piece, where the turbine tower is connected, is on the top of the jacket. The advantages of jackets are stiffness, low wave load compared to monopile, expertise of manufacturing jackets from the oil industry and the supply chain. Disadvantages include high initial manufacturing costs and possibly higher maintenance costs. Transportation can also be difficult and expensive, because of the size of the jacket. Jackets are suited for depths between 20 to 50 meters. (4Coffshore, 2013).

4.6 Pre-piling and post-piling

In pre-piling, templates are used to hammer the piles into the correct position in the seabed. When the piles are at the correct position, the jacket is lowered into the piles. The advantage of pre-piling is, that piling can be made far before the jacket is installed or parallel to jacket installations, which saves time and money. Also, there is no need for mud mats or pile sleeves.

When using the post-piling method, the jacket is lowered to the sea bottom and piles are installed in the sleeves, located at the jacket legs. With the grouting method, the piles are fastened to the sleeves and the load from the jacket is transferred to the seabed. (4Coffshore, 2013).

4.7 Suction bucket and caisson foundation

Suction bucket and caisson foundations are lowered in to the seabed, after which the water is pumped out of the foundation. This creates a negative pressure inside the bucket foundation and, with the help of the weight, the foundation starts to sink into the sea bottom. To easily remove the foundation from the sea bottom, the process can be reversed. This kind of foundation is fast and easy to install and does not require much preparation for the seabed. It is suitable for deep waters, large turbines and for several different types of sea bottoms. (4Coffshore, 2016).

4.8 Floating foundations

Floating foundations are used to get turbines even further out to the sea, where the winds are stronger and steadier. Embedded foundations, which are attached to the sea bed, cannot be used in deep waters. They would not be steady enough, too big and heavy and possibly not cost effective. Floating foundations are often semi-submergible constructions, which are attached to the seabed. The problem with floating foundations is, that they are usually much more expensive to manufacture and install. However when in working condition, the cost of energy can be cheaper than with fixed offshore turbines. (Martin, 2016).

5 Offshore wind farm maintenance and inspection

For the maintenance of offshore wind farms, it is very essential to have an expert team of engineers and technicians. Maintenance ensures that the turbines are running at highest capacity and efficiency. The turbines are complex systems, which require personnel who are highly trained and are able to work in demanding conditions, which often require rope access training. There is a general shortage of personnel with adequate experience in the business. (GL Garrad Hassan, 2013).

Maintenance of wind farms can be divided in preventative and corrective maintenance. Preventative or scheduled maintenance is done to components, which are known to wear and require maintenance or replacement at constant intervals. Condition monitoring systems give information about components, which need to be replaced before they break. Routine surveys and inspections are included in preventative maintenance. Routine maintenance and inspections are usually carried out during summer, when the wind speeds are typically lowest. Corrective or unscheduled maintenance is more of reactive repair work of critical components, which have failed or damaged. This kind of maintenance is hard to predict, but is always inevitable. (GL Garrad Hassan, 2013).

During the warranty period, it is usually the original equipment manufacturer (OEM) that has complete monopoly on the turbine maintenance. Spare parts for the turbine are usually also supplied by the OEM. After the warranty has expired, the owner can hire someone else to do scheduled maintenance and inspections. However, the OEM usually stays contracted in a smaller role for more technical, complex and unscheduled maintenance. (GL Garrad Hassan, 2013).

5.1 Foundation maintenance

The foundation of the wind turbine needs to be inspected and maintained from time to time. This is usually carried out by divers or ROVs (Remotely Operated Vehicle). The maintenance costs of offshore wind farms are much higher than onshore. The turbine and its foundation are submitted for harsh marine environment such as high winds, currents, waves and the corrosive effect of saltwater. Offshore, higher levels of reliability are required from the equipment to withstand the weather, which increases the manufacturing and maintenance costs. Foundation failures are not as common as electrical failures or other smaller faults in the turbine itself. However, foundation failures can be expensive and time consuming to repair, when often a jack -up vessel or other special vessels are required for the task. (Enterprise, 2017). When the foundation and turbine are installed and are in working condition, routine surveys are done during the first few years. After that, infrequent surveys are done. Also, some parts need to be changed when they are worn out, or at specific time intervals.

The foundation needs to be inspected for several reasons. Scour is sediment erosion caused by tides and currents, making the sand or other sea bottom materials to move away from the area, where the foundation meets the seafloor. Scour protection is often done with a rock installation vessel, which dumps gravel or other rock material with a fall pipe around the foundation. The fall pipe is often positioned by a ROV. Other methods for scour protection are piles, rubber mats or collars, which are placed around the foundation. The scour protection needs to be surveyed from time to time. The survey is done with a side-scan sonar from a survey vessel or with a ROV. If the rock has moved away from the foundation or the rubber mat is damaged, it needs to be replaced or repaired. (Rudolph, 2010).

The J-tube, which is the housing for the turbines electrical cable called array, connects the turbine to the offshore substation. J-tube guides and prevents the cable from bending too much as well as protects the cable from corrosion, wind, waves and currents. It can be internal or external, depending on the foundation type. The inspection of J-tube is usually done with a ROV. Other parts, which are affected by corrosion, include the splash zone at transition piece and the inner part of the monopile. The grouting, which cements the monopile and transition piece together, is not always fully air- and watertight and therefore corrosion is often developed inside the foundation. Some monopiles have a closed compartment, which is full of water and is meant to be airtight. However, sometimes oxygen leaks in and corrosion starts to occur. Also the cable entry sealing of the J-tube and weak welding's or joints can cause leakage. (Larsen, 2016).

To protect the foundation from corrosion, cathodic protection (CP) is used with galvanic anodes made of zinc or aluminium, which "sacrifice" themselves and corrode faster than the steel foundation. The anodes are welded to the foundations submerged and water level parts. The inspection of galvanic anodes is very important, because they need to be changed before the structure starts to corrode. The anodes can also be affected by excessive consumption, loss of contact or currents. Impressed current cathodic protection (ICCP) is used for long-term protection and is almost a maintenance free system. ICCP system is more effective, because there is a D/C power source, which "pushes" the electrodes forward in a controlled way from the anode to the cathode. Protective coating is used at atmospheric and splash zones. The splash zone coating needs to be very durable in order to last the whole lifetime of the foundation. Protective coating below water level is optional, but sometimes used to reduce the amount of cathodic protection. Galvanic anodes or protective coating is often used inside foundations to fight corrosion caused by leakage. Foundations are also affected by marine growth, which attaches itself to the metal. Marine growth has many negative impacts on offshore structures. It can affect the weight distribution or increase the drag coefficient and microbiologically influenced corrosion. Antifouling and other protective coating is used to protect the metal surface. Also, the ladder and platform of transition piece can get damaged by waves and might therefore need maintenance. (Britton, 2013).

The array power cable, which connects the turbines to the offshore substation, might also need maintenance. The movement created by currents and tides often affects the power cables, causing scour. In this case, more scour protection is needed to bury the cable under the seabed. Also, anchors might get stuck on the cable and damage it. The offshore substation foundation requires similar kind of maintenance as wind turbine foundations. (Enterprise, 2013).

5.2 Foundation inspection

There are several ways to inspect the foundation. Internal inspection of foundation can be done with corrosion coupons, which are used for visual evaluation and weight loss. Coupons can only show historical data of the corrosion instead of real-time information. Electrical resistance is used to measure real-time corrosion rates inside the foundation and in closed compartments of a monopile. Magnet-mounted reference electrodes measure the protection potential of the cathodic protection. Lowerable sensors, which measure pH, dissolved oxygen, temperature and resistivity, may also be used. Visual inspection is done to locate cracks and corrosion. It is still not known on how to inspect and monitor the inside of the foundation, especially the mud zone in the closed compartment of the monopile. For external foundation inspections, magnet-mounted UT crawlers are used. The device "crawls" on the wall, measuring the wall thickness of the transition piece above water level by using ultrasound. Drop-cell method measures the protection potential of the cathodic protection. (Britton, 2013).

5.3 Turbine inspection and maintenance

It is very important to inspect the erosion in the leading edges of the turbine blades, because it effects directly on the production of the turbine. Also cracks in the blades, structural damages, anemometer and warning lights for air traffic are inspected. Anemometer is a device used for measuring the direction and speed of the wind. It is placed on top of the turbine to measure the optimum direction of the turbine as well as the angle of the blades for the prevailing wind conditions. (Instruments, 2018)

Different methods are used for the inspection of the turbine, such as rope access, drone or ground based cameras. All methods have their limitations and choosing the right one depends on the scope of the inspection. For example, if only the blades are inspected, the use of a drone is usually the most effective method, instead of rope access. (E.ON, 2016)

The machinery inside the turbine nacelle is maintained regularly. The main parts of almost every turbine include a gearbox, shaft, brake and a generator. Lubrication is a very important factor for the operability of the turbine. It is needed for example for gearbox, generator bearings, blade bearings, main shaft bearings and yaw and pitch drives. When the parts are kept well lubricated, especially the gearbox, unnecessary and expensive repairs can be reduced. The lubrication oil is able to withstand extreme temperatures and corrosion caused by saltwater. Maintenance also includes filter changes, torqueing of bolts and electrical component failures. (Corporation, 2013).

6 Offshore wind farm construction in Finland

This chapter will describe the construction processes of two offshore wind farms in Finland: Kemi and Pori. The wind farms are both constructed in a unique way and the construction phases in both of the projects differ from each other. The wind farms in the North Sea are usually constructed on monopile foundations. In Tahkoluoto, a different solution regarding the foundations was used due to the sea bottom material and winter conditions. In Ajos, the foundations were built on artificial islands. In this chapter, both construction processes will be described in detail.

6.1 Construction of wind farm in Kemi

The construction project of wind farm in Ajos, Kemi started in November 2006. Altogether 10 wind turbines were installed, of which 8 were located offshore. Instead of building the wind farm to traditional offshore foundations, the turbines were built on artificial islands. The total energy production of this wind farm was 30 MW, making it the biggest wind farm at the time in Finland. The project included new working methods, such as the use of a temporary storage area in the harbour basin. The construction of the wind farm in Ajos was a sort of experimental project, with an aim to find a workable solution for future projects as well. The project was completed in September 2008, but the first turbine was already in operation in October 2007.

6.1.1 Construction of channels

Ajos wind farm construction project started with the construction of channels, which were used for the barge traffic during the project and for maintenance purposes later on. This was an important phase of the project, since the artificial island were located 0.5- 4 kilometres from the port of Ajos. Backhoe dredgers Kuokka-Pekka 2 (Picture 11) and Marika were used for this phase to carry out the dredging and Pora-Eero (Picture 12) for underwater drilling and blasting operations.

6.1.2 Construction of artificial islands

Most of the turbines were located 0.5 – 4 kilometres away from the port of Ajos. The water depth in the area, where the artificial islands were constructed, is 3-8 metres. In order to construct islands with a size of 30 x 50 metres, about 23,000 m^3 of blasted rock was used for each island. Additionally, about 3,000 m^3 of rock revetment, 6,000 m^3 of geotextile and 700 m^3 of concrete were used for the finalization of the islands.

In order to effectively carry out the transportation of the filling material for the islands, a temporary storage area was located in the harbour basin. Backhoe dredger was used to load materials from the storage area to barges, from where the material was further transported to the sites. The use of temporary storage area was a completely new solution and was found to be very effective; a lot of time was saved and stone dust was prevented from spreading into the environment.

6.1.3 Construction of foundations

When the blasted rock was compacted on the islands, the foundation was constructed. The foundation cylinder was installed in the middle of the foundation construction. In order to enable the access for the crane, maintenance quay as well as protection structures were built on the islands (Picture 10). The construction of the maintenance quay was essential, since it was used for the heavy lift, which was required for the lifting of the parts of the power plant.

Picture 10: Maintenance quay and construction of foundation on the artificial island (TerramareBoskalis, 2017).

6.1.4 Transportation of concrete

The concreting for the foundations was enabled with concrete transportation carried out by the barges. Steel containers, with a capacity of 30 m3, were installed on two of the barges, which then sailed between the islands and the harbour. When the concreting was done, the slopes of the islands were protected using crushed aggregate and rock revetment.

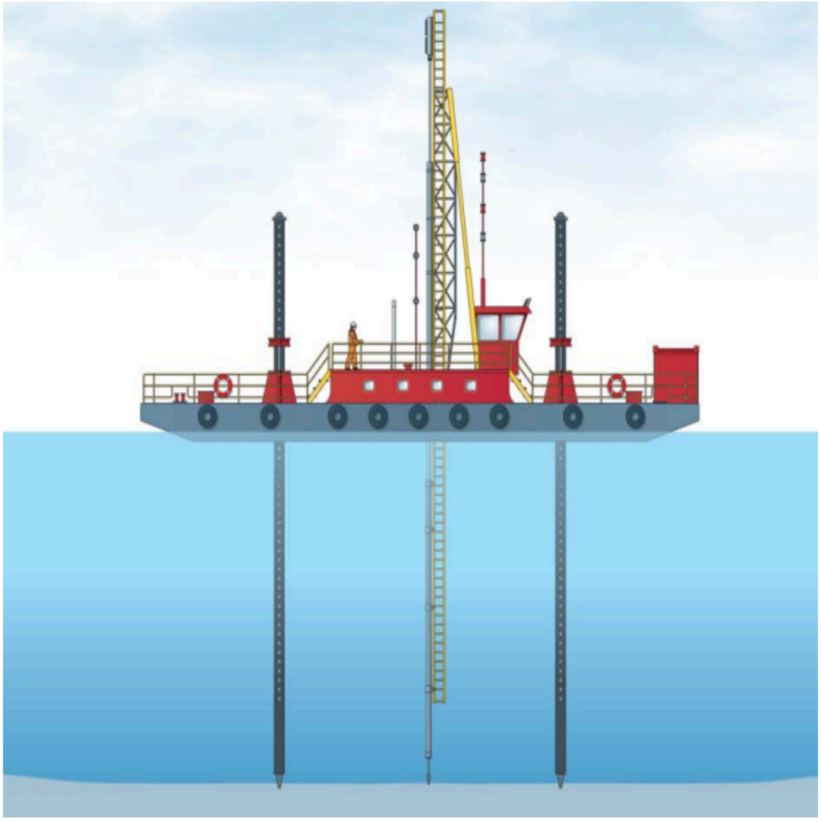
6.1.5 Vessels used for the project

All vessels, which were used for the project, were supplied by Terramare. Altogether 11 vessels, including dredgers, tugs, barges and platforms, were used. (Terramare, 2018).

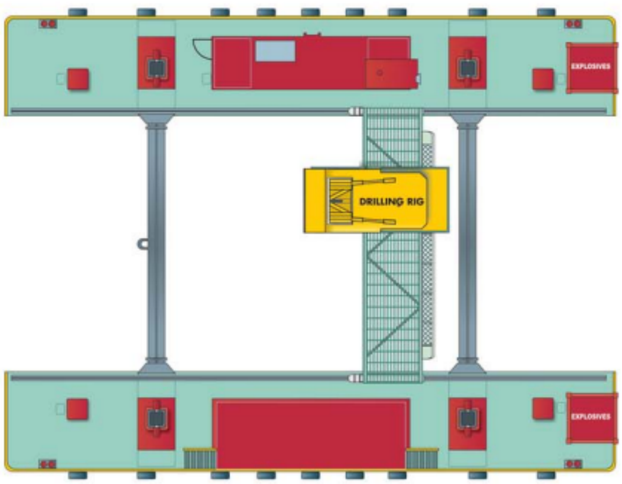
Kuokka-Pekka 2 (Picture 11) is a powerful backhoe dredger, which is capable of dredging all kinds of materials and can act even under heavy working conditions. It has a length of 31 meters, draught of 1,7 meters and dredging depth up to 14,5 meters. Depth for the spuds is 17,2 meters. (Terramare, 2018). During the construction of Ajos wind farm, backhoe dredgers Kuokka-Pekka 2 and Marika were used for the dredging of the channels in the beginning of the construction work, as well as for the handling of the filling material. (Terramare, 2018).

Picture 11: Kuokka-Pekka 2 (TerramareBoskalis, 2017).

The self-elevating drill barge Pora-Eero is equipped with a deck crane, four spud legs and a heavy-duty drilling rig, which is suitable for tasks demanding high performance and accuracy (Pictures 12 and 13). It has a length of 25 meters and depth of 2,2 meters. The depth for the spud legs is up to 18 meters (Terramare, 2018). In Ajos wind farm construction project, Pora-Eero was in charge of the underwater drilling and blasting operations (Terramare, 2018).



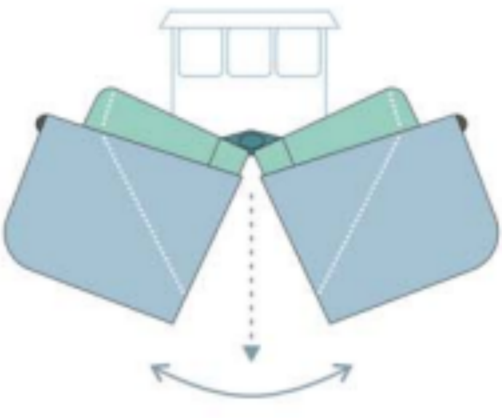
Picture 12: Self-elevating drill platform Pora-Eero (TerramareBoskalis, 2017).



Picture 13: Self-elevating drill platform Pora-Eero (TerramareBoskalis, 2017).

Self-propelled split hopper barges Adam, David, Cara and Tiukka were used for the transportation of filling materials (Picture 14). Split hopper barges have a large hold, which is used for material transportation. The split-hopper barges are efficient for accurate dumping of dredged material. A split hopper barge consists of two halves. By opening these two halves (Picture 15), the material is unloaded on the seabed. (JanDeNul, 2018). In Ajos wind farm construction project, the barges were loaded with the dredged material in the temporary storage area by a backhoe dredger, from where the material was delivered to the deposit area (Terramare, 2018).

Picture 14: Self-propelled split hopper barges Adam and David (TerramareBoskalis, 2017).



Picture 15: Barge in open position (TerramareBoskalis, 2017)

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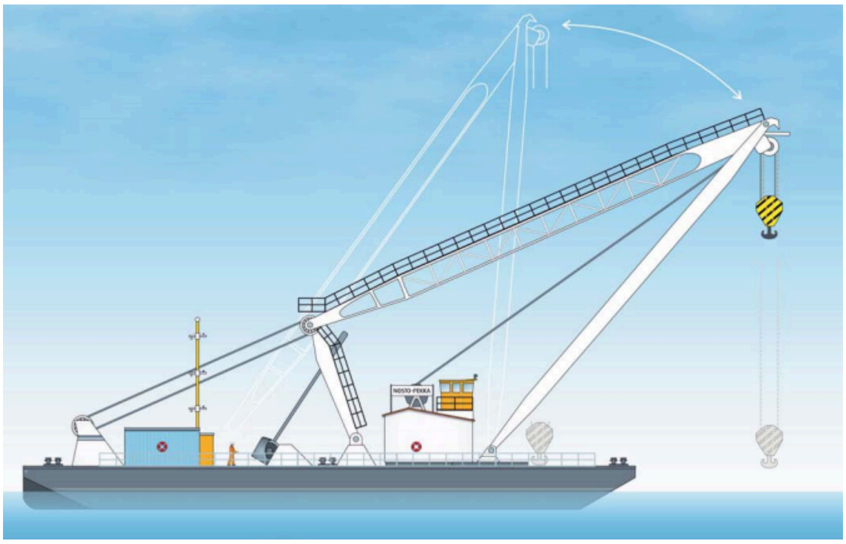
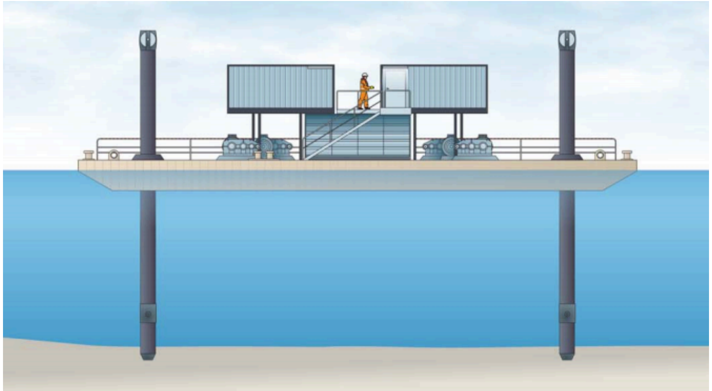
Nosto-Pekka is a heavy-duty floating crane (Picture 16), which is used for the transportation and installation of heavy quay elements. It has a length of 47 meters, draught of 2,6 meters and a lifting capacity of 200 tons (Terramare, 2018). In Ajos, Nosto-Pekka was used for the installation of quay wall elements on artificial islands (Terramare, 2018).



Picture 16: Floating crane Nosto-Pekka (TerramareBoskalis, 2017).

Working platform Paalu 1 (Picture 17) and drill barge Pora-Pekka 4 (Picture 18) were used to transport equipment and supplies to the artificial islands as well as used as work pontoons (Terramare, 2018). Work platform Paalu 1 has been mainly used for quay construction and piling works (Terramare, 2018). Pora-Pekka 4 is a semi-floating drill barge, which is built for underwater drilling and blasting purposes. It consists of demountable pontoons, four spud legs and a hydraulic drilling rig and can be converted to work as a crane platform. It has a length of 30 meters and a working depth up to 21 meters. (Terramare, 2018). Additionally, a tugboat Retu was used for crew transport and towing operations (Terramare, 2018).



Picture 17: Paalu (TerramareBoskalis, 2017).

Picture 18: Semi-floating drill barge Pora-Pekka 4 (TerramareBoskalis, 2017).

6.1.6 Situation today

In 2016, OX2 started working with the Ajos wind farm. This was a so-called repowering project. During the project, the existing turbines built on the artificial islands were replaced with more powerful and newer ones. Also, the existing sea cable was renewed and the substation was extended. All of the turbines were replaced, and the wind farm was extended with two new buildings. The efficiency of each turbine located offshore was increased to 3,3 MW and rotor diameter was extended to 130 meters. (OX2, 2016).

The repowering of the wind farm was carried out in co-operation with Siemens. Siemens has been working with various offshore projects, including also the construction of offshore wind farm in Tahkoluoto. (OX2, 2016).

Ajos wind power project was the first large-scale repowering project in Finland. The wind farm was handed to Ikea in October 2017. OX2 remains responsible for the management of the technical and commercial operation of Ajos wind farm. (OX2, 2016).

6.2 Offshore wind farm in Pori, Finland

The first offshore wind farm in Finland was built in Tahkoluoto, Pori and it was fully commissioned on 31^{st} August 2017. The wind farm consists of 10 turbines, manufactured by Siemens. The capacity of the wind farm is 42 MW and the project costs were about 120 million euros.

The wind farm was constructed during summers 2016 and 2017. The northern Baltic Sea differs from usual wind farm environment: the salt content of the water is lower and the wind speed does not rise as high as for example in the North Sea. For this reason, an altered model of a basic onshore wind turbine was used in Tahkoluoto. The model had a more reliable backup system for usage and data transportation in failure situations. (Miia Nurminen-Piirainen, 2015).

6.2.1 Pilot turbine

Before building the wind farm, Hyötytuuli Oy, which was the company leading the project, placed a pilot turbine to the area. The purpose of the pilot turbine was to see how the special conditions would affect the harvesting of the wind power and if it would be a profitable idea at all. The turbine was set up in 2010 and it has continued operating, while the rest of the wind farm was built. Today, it keeps gathering wind power alongside the rest of the turbines. (Hyötytuuli, 2018).

6.2.2 Construction of foundation pits

The first steps of the construction process were taken during June and July 2016, when the foundation pits were excavated with a dredger and the material was transported to a dumping area. The foundation pits were then filled with crushed rock and flattened in order to create a stable basis for the turbines, since they need to sit upright on the seabed.

Afterwards a survey vessel made sure everything looks as it should, and as it detected loose material on the foundation pits, the locations were recorded and compacted with a barge and a compaction weight. (Hyötytuuli, 2018).

6.2.3 Dredging of cable trenches

During July and August 2016, the trenches for the cables were dredged with a backhoe dredger. In the end of the dredging, a bathymetric survey was performed. A bathymetric survey can be compared to topography on land: it displays the different water depths with contour lines and soundings and by interpreting the survey results, the cable trench can be inspected to make sure there are no obstacles on the cable route. After this a winter break took place from August 2016 to March 2017. (Hyötytuuli, 2018).

6.2.4 Installation of foundations

During April and May 2017, the turbine components were transported near the wind farm site. The foundation pits were filled with a fine layer and levelled. During May and June, the foundations were loaded to the Vole Au Vent and the installation of the foundations began. (Hyötytuuli, 2018).

Installation of the foundations is a challenging task, since the foundation components need to be completely levelled to match the seabed. If the foundation is lowered to the seabed unlevelled, it will damage the compacted seabed and it will need to be levelled again before lowering the foundation component down again. For this purpose, a special X-frame lifting tool by SyncHoist was used. The X-frame was used to manoeuvre the foundation in high precision, while it was lifted from Vole Au Vent to its position. Manoeuvring was made possible with four push-pull hydraulic cylinders at each corner and a diesel hydraulic power pack. (Heavyliftnews, 2017).

Picture 19: X-frame (HeavyLiftNews, 2017).

When the foundations were placed to the sea bottom and filled with gravel as ballast filling, the foundations were lined with scour protection.

At the same time, the subsea cable was installed. After the cable was at place, it was checked with survey to make sure everything went well. The cable was then buried and surveyed once more. (Hyötytuuli, 2018).

6.2.5 Installation of turbines

During June and July, the components of two turbines were loaded at a time on board Vole Au Vent and then installed to their foundations. Vole Au Vent was capable of transporting all of the components for the two turbines at a time: the tower, nacelle and blades. She positioned herself next to the turbine foundation on the jack-up legs and lifted the tower onto the foundation, followed by the nacelle and blades.

During July and September, the turbines were commissioned and installed, and the final inspections were made. Wind Servant transported specialists to the turbines to perform the task. On the 31st of August the project was finished, a test period was completed and the take-over of the wind farm was celebrated. (Hyötytuuli, 2018).

6.2.6 Contractors and vessels involved in the construction

The main contractor of marine construction operations in the Tahkoluoto wind farm project was Jan De Nul NV, a Belgian offshore construction and installation company. They were responsible for the dredging, seabed preparation and installation of the turbines. The turbines were installed with their four-legged jack-up vessel Vole Au Vent.

The Finnish Sea Service was involved with the cable laying operations, Meritaito performed some of the 3D survey scans and divers installed the J-tubes. Guard vessel kept away the eager outsiders.

The turbines, which are suitable for winter conditions, were supplied by Siemens. The subsea cable, which is about 14 kilometres long, was supplied by Prysmian Finland. ABB was responsible of the electrical work and Technip Finland manufactured the foundation, which is able to handle the pressure of ice during winter.

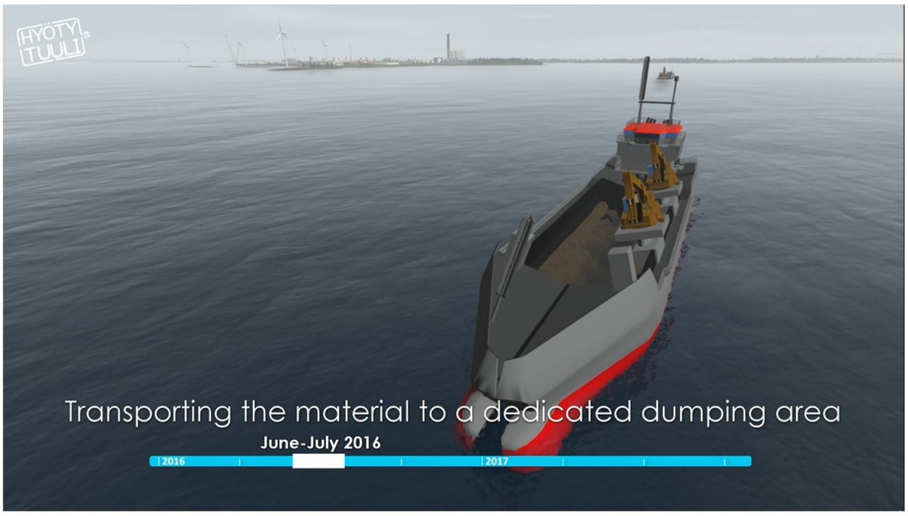
Altogether the project occupied 7-8 vessels and about 200 crewmembers (De Meulder, Marine Operations Manager in Tahkoluoto 16.01.2018). A description of some of the vessels, which were involved with the construction and installation process in the Tahkoluoto project, is found below.

Picture 20: Backhoe dredger Mimar Sinan (JanDeNul, 2018).

A backhoe dredger (Picture 20) is a hydraulic excavator placed on a pontoon. The dredger has three legs it uses to stabilize itself to the sea bottom, in order to use the excavator effectively and to prevent the pontoon from capsizing. The dredger excavates the soil and then loads it onto a split hopper barge, which is moored alongside. Mimar Sinan is a 64,9m long backhoe dredger, capable of dredging in water depths up to 32 meters. The capacity of the bucket is 40 m^3. (JanDeNul, 2018). Mimar Sinan was in charge of the excavation of the foundation pits and the trenches for the turbine cables (Hyötytuuli).

Picture 21: Split hopper barge Tiger (JanDeNul, 2018).

Split hopper barges are ships with an open hold, which is used for the transportation of dredged material. The soil which was excavated by Mimar Sinan, was loaded to Tiger (Picture 21) and then transported to a dumping area (De Meulder, 16.01.2018). The dumping is done by opening the barge in half and dumping the soil on the seabed (Picture 22). After dumping the excavated soil, Tiger transported crushed rock to the foundation pits, which were flattened afterwards to create the base for the turbine foundations.



Picture 22: Split hopper barge Tiger at the dumping area (Hyötytuuli, 2017).

Picture 23: Stone installation vessel Pompeï (JanDeNul, 2018).

Pompeï (Picture 23) is a stone installation vessel, which was used to install the scour protection to the turbine foundations, once they were placed on the seabed. Pompeï dumped crushed rock beside the foundations to protect them from scour (Picture 24). (JanDeNul, 2018).

Picture 24: Installing scour protection (Hyötytuuli, 2017).

Picture 25: Turbine installation vessel Vole Au Vent (JanDeNul, 2018).

Vole Au Vent (Picture 25) is one of the largest wind turbine installation vessels in the world. It is 140 meters in length, 41meters in breadth and has a Dynamic Positioning class 2 system. With space for cargo on deck and a crane with lifting capacity of 1500 tonnes, the vessel installed the foundations in Tahkoluoto (JanDeNul, 2018). After transporting and installing the foundations, Vole Au Vent loaded two turbine towers, nacelles and blades on board at a time and installed them (De Meulder, 16.01.2018).

6.2.7 Maintenance

Since the wind farm is new and has just started to operate, it is carefully maintained and inspected to investigate all possible faults, before anything develops into something serious (Hanna Matomäki, Project Leader, 16.01.2018). During winter, the maintenance crew will not visit the farm unless there is something alarming going on, even though the fairway to the site is kept open. During summer Wind Servant, (Picture 26) a specially constructed wind farm maintenance vessel, will visit the wind farm regularly and transport the maintenance crew to the turbines. Offshore support vessels, which are commonly used on the North Sea, are also capable of performing maintenance rounds to the wind farm. In case of a bigger problem, a jack-up vessel will be transported to the scene.

Picture 26: Wind Servant, a purpose-made vessel capable of attaching itself to the wind turbines (Auramare, 2017).

7 Challenges

One of our main goals in this thesis was to find out the challenges in the offshore wind farm construction and how these challenges are handled. This chapter is mainly based on an interview with Hyötytuuli and a public video interview about Ajos repowering project. Winter conditions, sea bottom and availability of vessels were the main challenges mentioned by Hyötytuuli. The construction site manager of Ajos repowering project stated, that the biggest challenge was the work at sea in the windy conditions as well as the restricted time available to carry out the work. In this chapter the challenges as well as the possible solutions are described.

7.1 Winter conditions

There are always extra risks and costs, when manufacturing offshore wind farms in cold climates. It is important, that the substructure and turbine are high quality in order to withstand several winters during their lifetime. Ice affects installation, operation and maintenance and critical components in the turbine always require backup systems in case of a failure. In freezing conditions, the lubrication oil does not flow well, which causes more friction and load. This has an influence on the power output and hence to the lifetime of the turbine. Therefore, special lubrication oils are needed in cold conditions. Ice on the leading edges of the blades can also reduce the power output and increase load and vibration, since the aerodynamics of the blades is affected already from minor freezing. In some cases, the whole turbine can even shut down in order to prevent equipment failure. The losses and failures in the cold climate could be minimized by improving the ice detection and forecasting systems (ieawind, 2016).

7.1.1 Ice protection systems and sensors

There are various types of rotor blade de-icing and anti-icing mechanisms, such as heating of the blades and anti-icing coatings. The ice protection system to be used depends on the location, turbine type and severity of ice conditions. Even if these kinds of systems are used, there is usually some reduction in the power output during harsh icing periods. The heating of the blades might not be powerful enough, or the essential ice detector on the turbine might malfunction and icing may occur on the blades. Ice detectors are used to control the anti-icing and de-icing systems in the turbine and the precautionary shutdown to protect the turbine at severe ice conditions. The reliability and response time of the ice detectors has been a problem because of the complex systems, but since the technology has recently improved, better results have been gained. The problem is often that the ice detectors are not able to measure the actual ice conditions at the rotor blades. Visibility detectors can also be used to detect ice. Also, the anemometer and wind vane are vulnerable for freezing and must therefore be often heated. Both cup and ultrasonic anemometers are used. A heated anemometer is often less accurate, because of the more compact size and reduced sensitivity. Some companies use both heated and unheated sensors, so that the heated sensor can be calibrated during periods, when freezing does not occur. For the heating of sensors and ice protection systems, a power supply is needed. The power can be provided from grid connection, batteries with diesel generator, solar panels, small wind generators or from a fuel cell (ieawind, 2016).

Turbine manufacturers produce models, which are more suitable for cold climates. They can have so called “cold weather packages”. The control system of the wind turbine can change certain parameters during freezing conditions and automatically activate ice protection systems. They often contain some kind of anti-icing and de-icing systems for heating of the blades, but also nacelle space and turbine components, such as the gearbox, brake, battery, sensors and yaw/pitch motors are heated. The systems used for the heating of the blades include electro-thermal heating elements, microwave ice protection coating or warm air circulation. Also, the steel in the foundation and turbine are cold resistant. The turbine nacelle needs to be properly sealed, so that moist and snow does not penetrate to the turbine machinery. Especially the electronics are sensitive for moist and need to be protected. A cold start function is also crucial, where the lubrication oil is heated, so that the viscosity is reduced, and sudden thermal heat expansion is taken into account (Canada, 2017).

Falling ice from the turbines is always a risk for the maintenance crew. During icy conditions it is important to take measures to minimize the risk of falling ice. Anti-icing and de-icing systems should be used and possibly even shut down the wind turbine (Canada, 2017).

7.1.2 Substructures in cold climates

Offshore wind farms in cold climate conditions require even stronger foundations than those, which are not affected by the cold harsh weather. The foundation must withstand huge ice masses colliding and compressing the structure. Packed ice can make the maintenance difficult and damage the upper parts of the foundation and the transition piece. It is important to take into consideration the form of the foundation in arctic conditions, since ice behaves and cracks differently depending on the form of the foundation at water level. A monopile foundation, which is long and cylindrical, takes a lot of hard hits from the ice, causing vibration and bending to the structure. However, in this kind of foundation the ice does not get stuck around it. (VTT, 1998).

Foundations, which have a formation like a cone at the waterline, are able to crack the ice at much smaller pressures and thus smaller amounts of stress is put on the foundation itself. Also, the dynamic pressure is much smaller. However, ice can more easily gather around the cone shaped formation and form high ice walls of several meters and even block the entrance to the turbine tower. (VTT, 1998).

Tahkoluoto is for now the only offshore wind farm in Finland constructed on foundations lying on the seabed. The foundations used in Tahkoluoto are special steel caissons, which are filled with gravel as ballast and are cone-shaped at the water level (Picture 27). They are installed in water depths up to 15 meters. The maintenance entrance is heated during winter, so that the ice does not block it and docking is possible. This kind of foundation is called gravity-based caisson. (Media, 2017).

Picture 27: Tahkoluoto foundations in Pori (Offshorewind, 2017).

7.2 Sea bottom challenges

The majority of European offshore wind farms are located in the North Sea. The sea bottom is optimal for hammering in monopiles, since in the North Sea the sea bottom tends to be muddy, sandy and soft, excluding the coasts of Scotland and Norway. (Mats Walday and Tone Kroglund, 2008).

The sea bottom on the northern Baltic Sea is rocky with a layer of soft mud on top, so the monopiles are not the optional foundation in this environment. For this reason, a gravitation-based foundation was used in Tahkoluoto. The project crew is now closely monitoring the behaviour of the foundations on the sea bottom for possible movement or tilting, but to date no problems have occurred (De Meulder, 16.01.2018).

7.3 Vessels

Building a wind farm requires a lot of unconventional vessels. In Tahkoluoto, the only vessel particularly designed for wind farm construction purposes was the Vole Au Vent: the jack-up vessel, which installed the foundations and turbines. All of the other vessels involved in the project were basic offshore construction vessels including cable laying vessels, dredgers, barges, survey and diver support vessels, rock dumping and guard vessels.

One of the problems facing the Finnish offshore wind energy industry is the lack of offshore vessels located in Finland, capable of performing the installations and maintenance of the wind farms. There are no wind turbine installation vessels located in Finnish waters ready to be used, compared to the North Sea where the supply meets the demand. Transporting a special vessel from the North Sea increases the project costs.

For example, in the Tahkoluoto project, almost all of the vessels were supplied by Jan de Nul, a Belgian contractor. None of their vessels were located in Finnish waters. By using Finnish contractors, the companies planning to construct an offshore wind farm can more easily receive financial assistance from the government (Hanna Matomäki, 16.01.2018).

The vessels used during Ajos wind farm construction project were all Finnish and supplied by Terramare Boskalis. Altogether 11 vessels were used including dredgers, barges and tugs. (Terramare, 2018).

7.4 Construction time

Construction site manager Eero Koskinen mentioned in his interview, that the most challenging part in the project was the work at sea. Wind and waves restrict the ability to work: high waves make it difficult to approach the artificial islands and wind restricts lifting operations. Eero Koskinen also mentioned, that one of the challenges in the construction of offshore wind farms in Finland is the limited time it is possible to carry out the work. Especially the time for the work offshore is very short: from June until the beginning of September. Also, there are many days, when the work cannot be carried out at all due to the weather conditions. (OX2, 2018).

Similar challenges were encountered in the Tahkoluoto project as well. The construction time was limited to only four months during summertime. Heavy lifts cannot be performed during windy days and due to the short construction time available, the project needed to be carefully planned and coordinated, in order to carry out multiple tasks simultaneously. (Hyötytuuli, 2018).

8 Conclusions

One of the biggest challenges in the construction of offshore wind farms in cold climate is the limited time available for the construction process. The working time is limited to only three to five months per year, before the winter begins and the conditions are too rough for the wind farm installation. For this reason, the installation of the turbines and working on the site needs to be executed only during the summer months, which affects the total duration of the project.

The availability of offshore vessels, capable of performing the construction and maintenance work, is limited in the northern parts of Baltic Sea, since the market for offshore wind farms has been more focused on the North Sea. The vessels needed for the preparation work in the construction of offshore windfarms, such as tugs, dredgers, working platforms and barges, are available in Finland. However, there are no specially designed vessels available in Finland, which are suitable for the installation of turbines, such as Vole Au Vent.

Both offshore wind farms in Finland are constructed in a unique way. Monopile foundations, which are commonly used, are not the most suitable solution to icy conditions nor the type of sea bottom in Finland. For this reason, gravity-based foundations were used in the Tahkoluoto project. In Ajos, the foundations were built on artificial islands and therefore do not have structures under water. The winter conditions, such as the stress from compacted ice, do not therefore affect them as much as in Tahkoluoto.

Icing of the turbine blades creates extra load on the turbine and thus, decreases the production. Also freezing of the lubrication oils cause wear to the turbine parts. Sometimes in very icy conditions the turbines shut themselves down to prevent damage to the turbine. This precaution prevents the parts from breaking down, but also causes losses in the production. Even if the oil can be heated and de-icing systems are used for the turbine blades and nacelle, these problems caused by ice decrease the lifespan and production value of the turbine.

The wind farm in Tahkoluoto, Pori, is the first wind farm in the world designed to ice conditions. Since the construction was finished in August 2017, this is the first winter it is experiencing. Even though the foundations are now constantly being monitored, it will take years to see the long-term effects of the winter conditions and the behaviour of the foundations in the sea bottom.

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