Feasibility study offshore wind energy

ELWIND

Ministry of Economic Affairs and Communications of Estonia and
Ministry of Economics of Latvia

721104 | Final report

16-12-2021

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1 Introduction

1.1 The ELWIND project

In September 2020, the Minister for Economics of Latvia and the Estonian Minister of Economy and Infrastructure signed a Memorandum of Understanding on the joint project of an offshore wind farm for energy production from renewable energy sources. The project was dubbed Estonia-Latvia WIND, or ELWIND in short. ELWIND project is an Estonian-Latvian joint hybrid renewable energy project concept in Baltic Sea. The total capacity of planned offshore wind park is 700 - 1000 MW, which will provide over 3 terrawatt-hours (TWh) annually. The ELWIND project is planned to be operational in 2030.

1.1.1 Relevant climate goals

To achieve the goals of the European Green Deal, the Baltic states are in a position of urgent need to redesign their energy sector.

Both countries have committed to the European climate change goal to reduce greenhouse gas emissions to at least 55% below the 1990 levels by 2030, and to become completely climate neutral by 2050.

Estonia

- Achievement of an 80% reduction in GHG emissions by 2050 (including 70% by 2030).
- The share of renewable energy in total final consumption must be at least 42% by the year 2030: In 2030, production of renewable energy will be 16 TWh, which is 50% of the final energy consumption, including 4,3 TWh of renewable electricity (2018 = 1,8 TWh).
- Estonia’s economy is growing, so significant measures are needed to keep consumption at the same level. The general energy saving objective of 14,7 TWh for the period 2020-2030 applicable under Directive 2012/27/EU (the Energy Efficiency Directive) will help keep final energy consumption at the same level. Making primary energy consumption more efficient will help reduce energy consumption.
- Meeting the minimum criteria for interconnectivity of electricity grids: Increasing capacity towards Latvia and synchronising the power grid with the Central European frequency band by 2025.

Latvia

- Emissions in Latvia in 2030 should be less than 45 % of the total GHG emissions in Latvia in 1990
- The share of RE in Latvia's final energy consumption should be at least 45 % by 2030.
- Latvia must ensure the interconnection capacity of 80 % (the ratio of interconnection capacity to the total electricity capacity of Latvia) and take into consideration the demand for higher capacity of the neighbouring countries with whom the interconnections are established.

Summarizing, both countries have ambitious climate goals, in line with general EU guidelines. Moreover, the interconnecting of both countries is a significant goal for both countries. The ELWIND project, which consists of a joint offshore wind project – and possibly includes an offshore interconnector – plays a significant role in reaching these goals.

1.2 Purpose of the study

This report is a prefeasibility study on the pre-selected areas of the Baltic Sea Wind Farm (ELWIND). The main purpose of this report is to assess the pre-selected areas and point out the best location for a wind farm in the combined Estonian Latvian maritime areas. We assess and model several preselected offshore wind park development sites (4 sites, each ca 200km2, assuming capacity density of 5-8MW/km2) in the Baltic Sea within the Estonian and Latvian territorial waters and their exclusive economic zones. There are several criteria, based on which each wind area site is provided a score and assessment. In the conclusion of this report, a total score is given to each area, based on the cumulative assessments of criteria.

1.3 Reading guide

Chapter 2 provides an overview of the wind farm sites that are evaluated in this study. This chapter also provides an explanation of the reference turbine that is used in this study. Finally, in chapter 2 we discuss the impact of a grid connection on a wind farm’s costs and feasibility, and how this factor is assessed in this report.

A list of criteria and how they are assessed can be found in chapter 3. This chapter also contains the assumptions and extrapolations that had to be made in this report, as well as a list of gaps in knowledge that we acknowledge.

In chapter 4, each criterium is analysed based on the aforementioned methodology in chapter 3. A brief introduction on each subject is given and its relevance to the development of a wind farm summarized. The available data and its origins are also discussed here. Each wind farm site is given an assessment and possible mitigating measures are explained.

In chapter 5, all scores from chapter 4 are summarized and a final recommendation is given.

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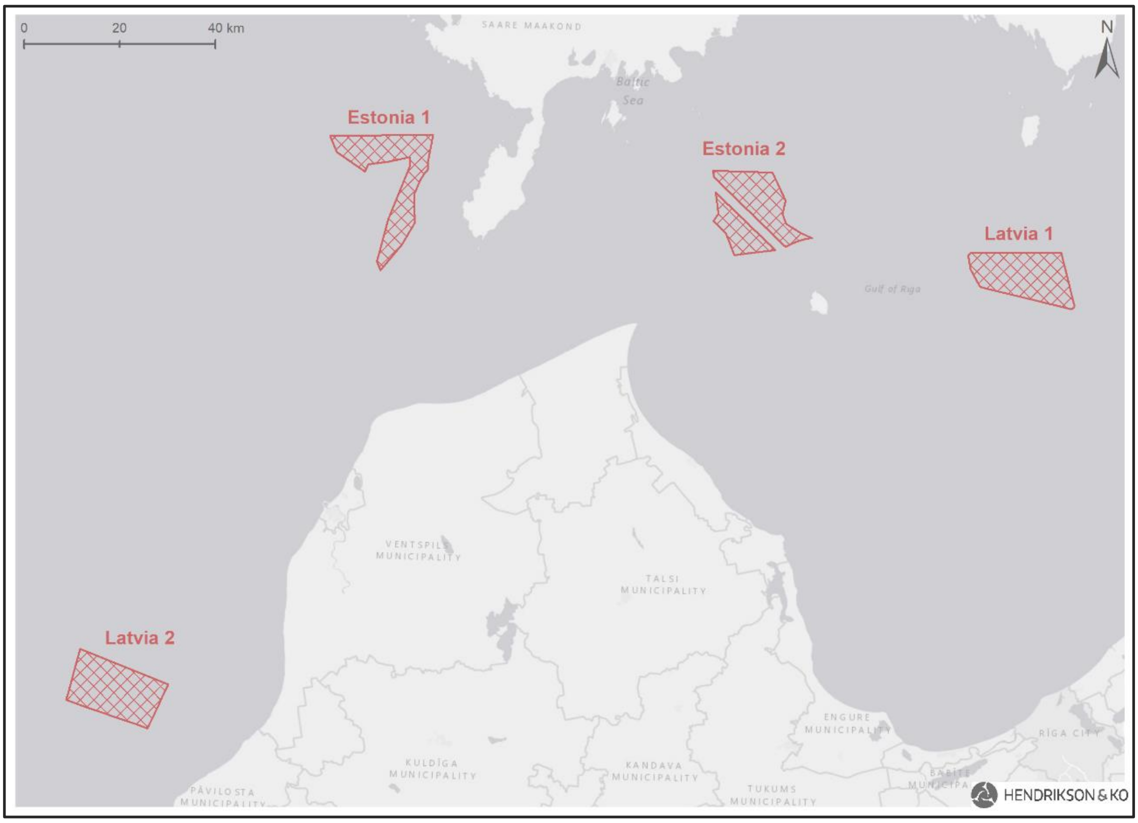
2 Wind farm sites and grid connection

2.1 Wind farm site descriptions

For this feasibility study four wind farm sites are assessed. Two wind farm sites are in Estonian waters and two in Latvian waters:

- Wind farm site Estonia 1 is situated on the west coast of Sõrve peninsula. The area is 197,8 square kilometres.
- Wind farm site Estonia 2 is situated in the north-western part of Gulf of Riga. The wind farm site is divided in two by a shipping route. The combined area is 194,7 square kilometres.
- Wind farm site Latvia 1 is situated in the north-eastern part of Gulf of Riga. The area is 183,8 square kilometres.
- Wind farm site Latvia 2 is situated near the west coast of Latvia. The area is 200,1 square kilometres.

Figure 2.1 Wind site overview



2.2 Reference turbine

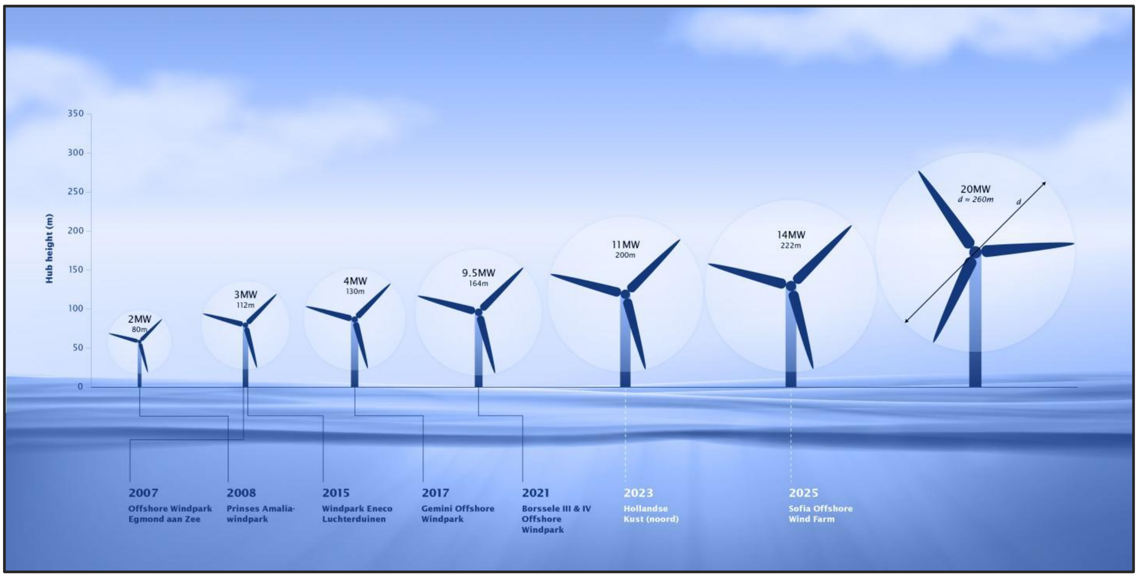
For some of the criteria examined in this report, the dimensions, such as the height and rotor diameter of the wind turbines are important. Because the offshore wind industry is constantly innovating, we use a "reference turbine" in this report (see table below). This turbine is fictitious: it does not exist yet. But the dimensions are based on the expected growth of wind turbines in the offshore wind industry. Wind turbine size is increasing rapidly, because the rotor area determines how much energy a wind turbine

can harvest from the wind. Since the rotor area increases with the square of the rotor diameter, a turbine which is twice as large will receive four times as much energy.
It is important to realize that calculations and figures in this study, based on this reference turbine, may change in the future. Based on this reference wind turbine the total amount of wind turbines in the four wind farm sites are approximately 110 (average of each wind farm site) (2.200 MW per wind site total).

Table 2.1 Reference wind turbine dimensions and features in this study

Reference turbine	Feature
Power (in MW)	20 MW
Hub height	165 meters
Rotor diameter	275 meters
Tip height	302,5 meters

Figure 2.2 Offshore wind turbine sizes. Source: van Oord (2021)



2.3 Grid connection

A large part of the cost of a wind farm consists of the connection to the high-voltage grid. The grid operators and governments of Estonia and Latvia are currently investigating the various possibilities of not only connecting a potential wind farm to the mainland, but also creating a connection between the two countries. Assessing the complexities that come with an international grid connection is a major project, and the inclusion of such an interconnection is therefore not within the scope of this study. However, for each criterium, in cases where it is relevant, the possible implications for the construction of a cable connection to the wind farm will be indicated.

3 Criteria and methodology

3.1 Overview of criteria

An overview of the assessed criteria and the methodology is listed in the table below. The weight of each criterion was indicated by the client at the start of the project.

Table 3.1 Overview criteria and methodology

Criterium	Methodology	Weight
Icing conditions	Each wind farm site will be provided a score based on the ice coverage and ice thickness.	8%
Water depth	Each wind farm site will be provided a score based on the water depth.	5%
Waves and currents	Each wind farm site will be provided a score based on the velocity of the currents and the wave height.	5%
Soil conditions	Each wind farm site will be provided a score based on the presence and approximate depth of weak seabed conditions in the top layers and deeper stone and rocky layers.	7%
Wind Speed & Capacity factor	The evaluation of this criterium will be based on the electricity production of each wind farm site.	9%
Foundation options	The feasibility of different foundation options is assessed, based on the site-specific conditions of each wind farm site	2%
Ports	Each wind farm site receives a score based on their relative proximity to a port that has the base requirements for supporting the logistics in constructing an offshore wind farm. Another factor is whether any locations for an O&M port are close by.	2%
Defence, surveillance, communication, and air traffic	Each wind farm site receives a score based on their effects on defence areas, surveillance/communication devices and air traffic.	5%
Shipping routes	The evaluation of this criterium is based on the amount and intensity of shipping routes that are in or near the wind farm sites	1%
Additional capacities / impact on other parks	Each wind farm receives a score based on the effects on other planned wind farms or wind farm areas. While positive synergy is possible – a grid connection can be shared – these effects can also be negative in the case of wake effects and the cumulative negative effects of other wind farms.	2%
Fisheries and impact on fish	Each wind farm site will be provided a score based on the fishing intensity and presence of fish and fish habitats.	2%
Birds	Each wind farm site will be provided a score based on the occurrence of birds and the presence of nearby bird migration routes and bird habitats.	4%
Bats	Each wind farm site will be provided a score based on the presence of nearby bat migration routes.	4%
Seals	Each wind farm site will be provided a score based on the presence of seals habitats and migration areas	4%
Nature protection areas	Each wind farm site will be provided a score based on the presence of Natura 2000 areas or other nature protection areas	4%
Onshore visual impact	Average visibility of each wind farm site is assessed and the population within distance calculated. Moreover, the number of touristic and social places of interest is considered.	1%
Total weight		**65%**

3.2 Evaluation method

The evaluation of each criterium is ultimately summarized in a single number, or score. For each criterium, each wind farm site receives a score based on the effect that criterium has on its feasibility. We will use a 1 to 10 scoring system for each criterium, which is then multiplied by the weight from Table 3.1.[1] A score of 1 means that a criterium poses very significant obstacles for the development of a particular wind farm site. A score of 10 indicates a very small chance that this criterium will pose a serious obstacle for wind farm development – be it due to high costs, complex design requirements, planning problems or overlapping interest with stakeholders. The given scores are based on:

- The available data: GIS, stakeholder information, scientific articles, or publicly available sources.
- An expert judgement, based on the experiences with other wind farm sites in the North Sea.

The final grade is weighted, based on the scoring table provided by the client. These weights are shown in the final column of Table 3.1. For example, wind area A might score 6/10 for shipping routes, and wind area B scores an 8/10. In the final score, wind area A would receive a score of 0,6 (60 * 1%) and wind area B would receive a score of 0,8 (80 * 1%).

The scores for all criteria are then summed up and rounded to two decimals, for a final score. This method allows for a more detailed comparison between different wind farm sites, particularly for criteria that have a 1 or 2 percent weight. If only the percentages were used, differences between the wind area sites are not clear from the scores, possibly suggesting a similar feasibility while this is not the case.

The exact assessment factors per criterium are described separately in each paragraph in chapter 4.

3.3 Assumptions and gaps in knowledge

Assumptions and incomplete data

This study uses several sources of data which were gathered from a variety of institutions and government agencies from Latvia and Estonia. Additionally, scientific articles and publicly available (geo)data was used to assess the feasibility of each wind farm site.

There are cases where the data is not complete, or where the resolution of the data differs for each (or some) wind area sites. In these cases, making a fair comparison between the different wind area sites is complicated (‘comparing apples to oranges’). To address this, we follow a simple method:

1. If, based on the other available data and/or our expert judgement, we can extrapolate and/or assume (relatively reliable) data, we will do so. This is always mentioned in the respective chapter.
2. If we cannot make an adequate assessment, this is mentioned in the chapter and the score will be the same as the lowest other score from other wind area sites.

[1] The total weight sums up to 65%. This is not an error. In an earlier version of this document, the total weight was 100%. However, one of the criteria was removed from the assessment.

Gaps in knowledge

For some criteria, it might not yet be clear what the effects of specific conditions on the feasibility of a wind farm site are. In these cases, this is mentioned in the paragraph of the criterium.

3.4 Disclaimer

Pre-feasibility

This study is a pre-feasibility study for the ELWIND offshore wind project. Each criterium that is covered in this study could be the subject of a stand-alone research report. This means that, by its nature, the conclusions and results in this report are generalized and should be interpreted as such. Further research, in a later stage of development is needed to make more specific assessments on the effects of each criterium.

Scores do not tell the full story

The scores for each criterium are a summary of the paragraph that precedes it. A single number cannot show all the intricacies and factors that were considered in making an assessment score. We feel it is important to mention that, while the final scores give a good overview of the feasibility of each wind farm site, the scores should always be interpreted in conjunction with the textual explanation.

4 Analysis per criterium

4.1 Icing conditions

4.1.1 Introduction and methodology

Ice conditions in the Baltic Sea are generally of moderate intensity and depend mainly on the type of winters (mild, average/ normal, and severe), however, the shallow parts of the Baltic bays and gulfs are covered by sea ice almost every year. The issue of freezing seas, the formation of sea ice, the drift ice floe, and the movement of the masses of ice are areas of interest in the development of offshore windfarms. The effects of ice on wind farm development are twofold: effects during construction and maintenance and the effects on the wind farm design. Ice conditions have no impact on the grid connection because the grid is placed or buried on the non-frozen seabed and the construction can take place outside of the winter period.

Construction and maintenance

During construction and maintenance, ice coverage has an impact on the accessibility of the wind farms. The ice conditions are only present during the winter season. Therefore, the planned construction activities and maintenance can be planned outside of the ice critical winter period. Unplanned maintenance activities could be restricted due to ice conditions during the winter. It would not be cost efficient to use an ice breaker to access the wind farm by ship and there are no existing ice-free routes in the Gulf of Riga headed towards the four wind farm sites. However, every wind turbine can also be accessed with a helicopter for small unplanned maintenance, although that is very costly. To conclude, the effects of ice conditions during the construction and maintenance phase are limited but can cause a longer inactivity of certain wind turbines that cannot be accessed for some time for maintenance.

Influence on wind farm design

The ice coverage, and especially the movement of ice masses, have a great impact on the design of a wind turbine and its foundation. Especially during the formation and breaking of ice, the movement of ice masses takes place. The velocity of ice movement depends on the wind speed, current speed, and spatial distribution of ice. The impact and force of ice movements on offshore wind turbines with such velocities depends on the size and thickness of the ice. A foundation of a wind turbine needs to withstand these forces over the lifetime (approximately 25 years) of the wind farm. Therefore, the annual ice cover and ice thickness is assessed in this study.

Beforehand, we can already exclude some foundation types that are not feasible in ice conditions (see paragraph 4.6 for a further description and assessment). The exclusion of foundation types and the requirement for larger, stronger, or stiffer foundation types impacts the business case and development of the offshore wind farm.

Another impact from ice conditions is ice forming on blades. Light icing can produce additional surface roughness on wind turbine blades that can reduce their aerodynamic efficiency. More icing results in a forced stop of a wind turbine to prevent damage on the wind turbine blades, generator or other components. Modern wind turbines are equipped with an ice detection system.
Mitigation measures can include passive systems such as ice-resistant coatings and active ones such as hot air or electro-thermal systems[2]. The impact of blade icing depends on the frequency, duration,

[2] https://www.windpowerengineering.com/cracking-icing-problem-turbine-blades/

severity, and intensity of icing which varies from year to year, site to site, and turbine to turbine. This aspect is not further assessed in this study.

Assessment framework and scores

Each wind farm site will be provided a score based on the expected ice coverage and ice thickness in the wind farm sites. Wind farm sites with a high ice coverage and high ice thickness will be given a low score. Wind farm sites with a low ice coverage and low ice thickness will be given a high score.

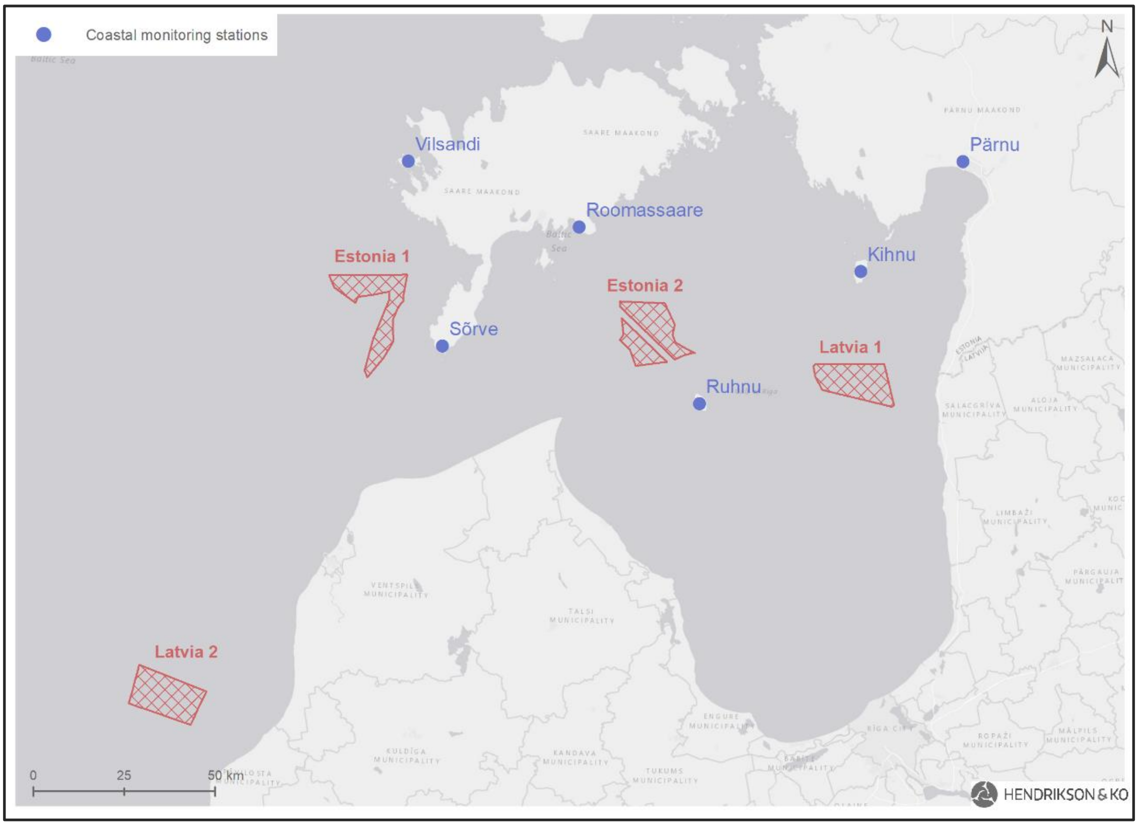
4.1.2 Data overview and description

The source info for icing conditions originates from Estonian Environment Agency observation data from 1980 to 2008. To support the Estonian Environment Agency observation data a 2017 scientific publication "Analysis of Ice Conditions in the Baltic Sea and in the Puck Bay" by Czesław Dyrcz is used.

Wind farm sites Estonia 1, Estonia 2 and Latvia 1 can be assessed by average ice days and ice thickness with the data provided by the Estonian Environment Agency. This data is measured at coastal meteorological stations. The wind farm sites are located further towards the open sea, where the icing conditions are expected to be less severe. The assessment based on the measurement data is therefore a worst-case approach.

For assessing the icing conditions in Latvia 2 area additional scientific publication and expert judgement was used to make general assumptions.

Figure 4.1 Estonian coastal monitoring stations



4.1.3 Assessment of wind farm sites

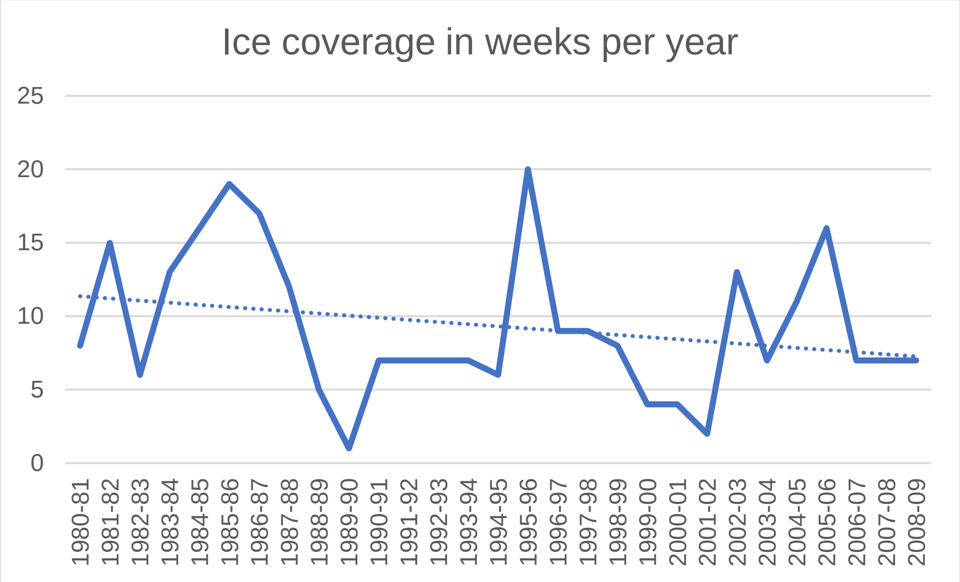
Wind farm site Estonia 1

The meteorological station on the Sõrve Peninsula is near wind farm site Estonia 1. In the graph below the total duration of ice coverage in weeks per year is displayed from 1980 until 2008. The duration of ice coverage starts from permanent ice formation until final de-icing. The maximum duration of ice coverage is 20 weeks, and the minimum is 1 week.

Ice thickness has not been consequently measured or reported in the used dataset. Generally, in the 80's the average maximum measured ice thickness during winter season near Sõrve station is 37 centimetres. In the 00's the average ice thickness is 23 centimetres.

Clearly, a downward trend is observed for both ice duration and ice thickness over from 1980 until 2008.

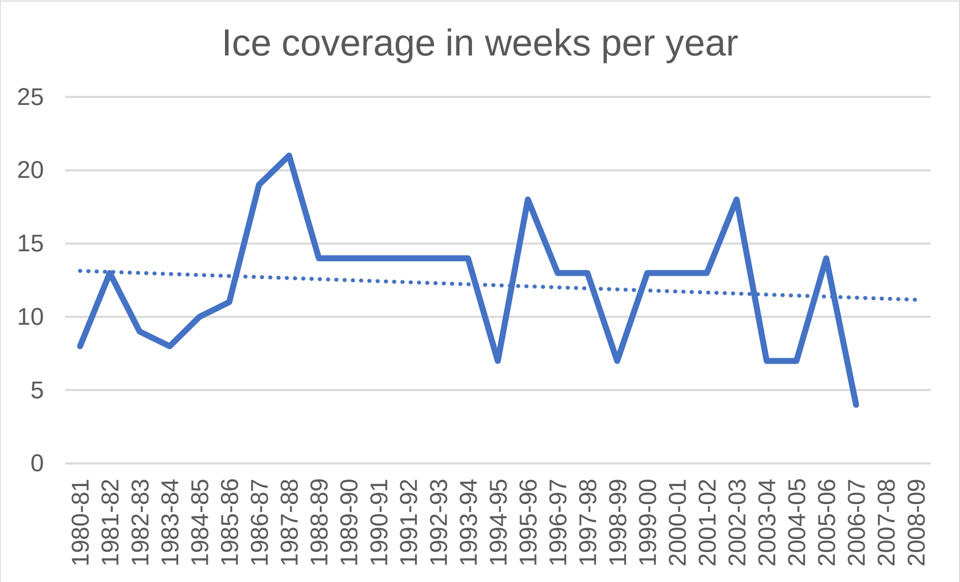
Figure 4.2 Sõrve meteorological station



Wind farm site Estonia 2

The meteorological station in Ruhnu is near to wind farm site Estonia 2. In the graph below the total duration of ice coverage in weeks per year is displayed from 1980 until 2008. The duration of ice coverage starts from permanent ice formation until final de-icing. The maximum duration of ice coverage is 21 weeks, and the minimum is 4 weeks.

Figure 4.3 Ruhnu meteorological station



Ice thickness have not been consequently measured or reported from 1980 until 2008 in the used dataset. Generally, in the 80's the average maximum measured ice thickness during winter season near Ruhnu station is 48 centimetres. In the 00's the average ice thickness is 32 centimetres.

Clearly, a downward trend is observed for both ice duration and ice thickness from 1980 until 2008.

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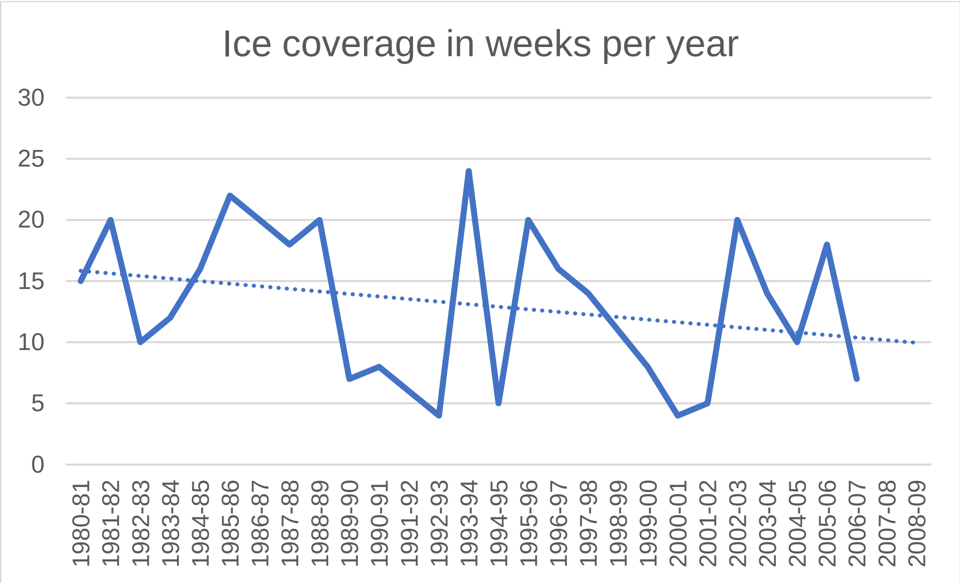
Wind farm site Latvia 1

The meteorological station in Kihnu and Ruhnu is near to wind farm site Latvia 1. For the ice conditions on Ruhnu, see the previous subparagraph. In the graph below the total duration of ice coverage in weeks per year is displayed from 1980 until 2008 on station Kihnu. The duration of ice coverage starts from permanent ice formation until final de-icing. The maximum duration of ice coverage is 24 weeks, and the minimum is 4 weeks.

Ice thickness has not been consequently measured or reported from 1980 until 2008 in the used dataset. Generally, in the 80's the average maximum measured ice thickness during winter season near Kihnu station is 48 centimetres. In the 00's, the average ice thickness is 15 centimetres.

Clearly, a downward trend is observed for both ice duration and ice thickness from 1980 until 2008.

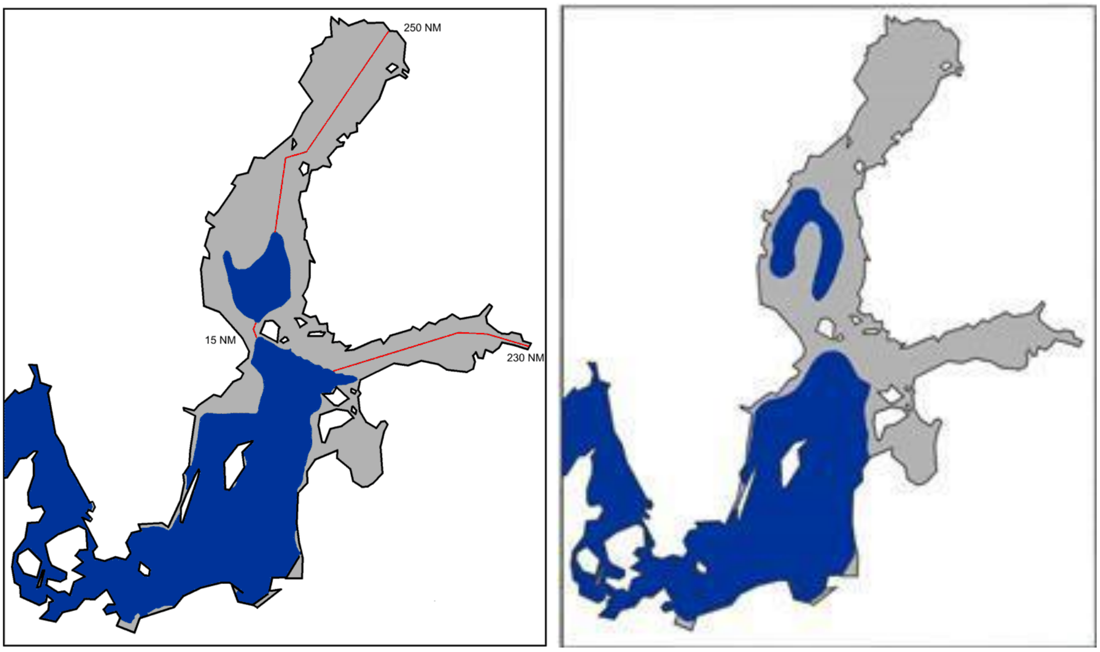
Figure 4.4 Kihnu meteorological station



Wind farm site Latvia 2

Wind farm site Latvia 1 is more located in open water compared to the other wind farm sites located in the Gulf of Riga. Unlike, the Baltic bays and gulfs, the open waters of the Baltic Sea are not covered with sea ice every year. Figure 4.5 shows that wind farm site Latvia 2 is not frozen during normal winters. However, ice conditions are present during severe winters. In conclusion, the long-term ice coverage and thickness is lower in wind farm site Latvia 2 compared to the other wind farm sites of this study.

Figure 4.5 Examples of typical maximum ice extents on the Baltic Sea during normal winters of 2012/2013 (left) and 2002/2003 (right). Grey is ice and blue is non-frozen sea.



Source: Dyrcz (2017), Analysis of ice conditions in the Baltic Seas and in the Puck Bay

Climate trends

In the assessment the historic data of ice coverage and ice thickness is used. We can see in the ice data of Estonia 1 and 2 and Latvia 1 that the trend of the last decades is a decrease of ice coverage and ice thickness. We can assume that this trend continues in the coming decades for all wind farm sites, including Latvia 2. Therefore, the current assessment based on historic data is a worst-case scenario.

In 18 years (1990 – 2008), the number of weeks with ice cover around the meteorological station of Sörve, Ruhnu and Kiknu decreased with respectively 41,7 %, 37,5 % and 15,4 %. Scientific literature is more conservative regarding historic trends of ice duration. Jevrejeva (2000)[3] states that the number of days with ice have decreased in the last century with approximately 5–10 days in the Gulf of Riga. If these trends continue in the future, this will have a positive impact on the development of wind energy in Estonia and Latvia.

4.1.4 Mitigating measures

Possible mitigating measures are using and designing larger and stronger foundation types, for example a jacket, suction bucket, gravity-based structure or very large monopiles (see paragraph 4.6 for a further description and assessment). Floating wind energy and small-dimensioned (small/thin-walled) monopiles are not feasible in ice conditions.

The effects of ice conditions during the construction and maintenance phase are limited. Therefore, measures to sustain the access to the wind farm sites (for example ice breakers) are not considered to be necessary.

[3] Jevrejeva, S. (2000) Long–Term Variability of Sea Ice and Air Temperature Conditions Along the Estonian Coast.

4.1.5 Conclusion

The identified ice conditions have an impact on the design of a wind turbine and its foundation. Large movements of thick ice require a very strong and stiff foundation type. Beforehand, we can already exclude some foundation types that are not feasible in ice conditions, like floating wind energy and thin-walled monopiles. The exclusion of foundation types and the requirement for larger, stronger, or stiffer foundation types impacts the business case and development of the offshore wind farm.

The final scores for the criterium ice conditions are listed in Table 4.1. The ice conditions of wind farm sites Estonia 2 and Latvia 1 are similar, which are in the middle of the Gulf of Riga. Wind farm site Estonia 1 and Latvia 2 are located more in the open Baltic Sea. This part of the Baltic Sea is only frozen during cold winters.

The measured ice coverage of Estonia 1 is lower than Estonia 2 and Latvia 1. The ice coverage and ice thickness of wind farm site Latvia 2 is expected to be lower compared to the other wind farm sites. However, during severe winters, Latvia 2 also suffers the consequences of ice conditions.

Table 4.1 Scores ice conditions (criterium weight = 8%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	7	4	4	8

4.2 Water depth

4.2.1 Introduction and methodology

The developers of offshore wind farms endeavour to exploit favourable geographical conditions wherever possible to limit the costs of foundations. The water depth of wind farm sites has effects on the construction methods and the foundation options. Deep waters result in a more complex construction method, larger and stronger foundations and therefore, higher costs. Most European offshore wind energy projects are in water depths up to approximately 40 meters. Above 60 metres of water depth bottom fixed foundations are not considered to be feasible.

Water depth is not a significant criterium related to the grid connection route. Only if the grid is construction in areas with a water depth higher than approximately 100 meters, water depth has a significant impact. This is because the cable must carry its own load when a cable is hoisted from a construction ship. When depths reach 100 meters or more, the cable must be engineered to withstand those forces when it is hoisted to the seabed. None of the wind farm sites and grid connection routes have a water depth higher than 100 meters.

Assessment framework and scores

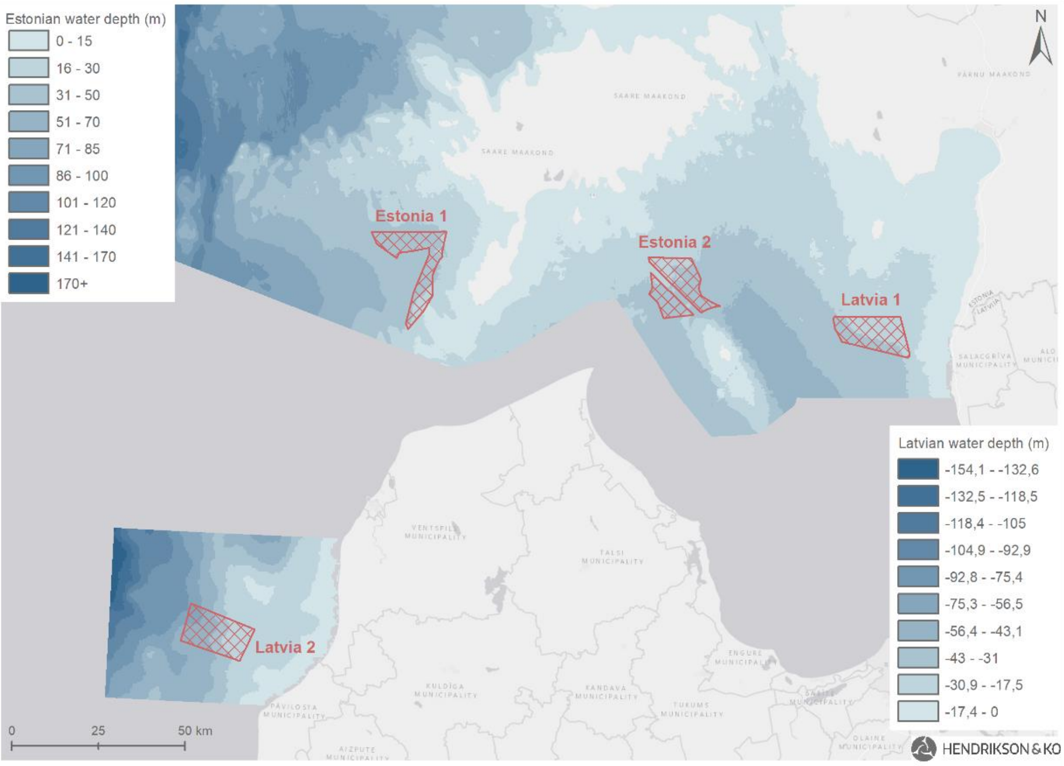
Each wind farm site will be provided a score based on the water depth. Wind farm sites with a higher water depth will be given a low score. Wind farm sites with a low water depth will be given a high score.

4.2.2 Data overview and description

Water depth data for both Estonia and Latvia originate from the Maritime Spatial Plan source data packages provided by the Estonian Ministry of Finance and the Ministry of Environmental Protection and Regional Development Republic of Latvia. Data for the Latvian wind farm sites was acquired from a public domain - The Baltic Sea Hydrographic Commission.

All wind farm sites are covered with water depth information. The main difference between the Estonian and Latvian datasets is the depth ranges, but overall, the water depth ranges are rather similar with approximately 15 or 20-meter step.

Figure 4.6 Water depth



4.2.3 Assessment of wind farm sites

Wind farm site Estonia 1

The water depth in wind farm site Estonia 1 ranges from approximately 17 to 45 meters. Especially the south-eastern side is shallower compared to the northwest. Approximately 15 percent of the wind farm site has a water depth between 17 and 30 meters. The other 85 percent is between 30 and 45 meters.

The average water depth is common for offshore wind farm developments. A wide range of foundation options are feasible and cost-effective for these water depths (see paragraph 4.6 for the foundation options). For example: the most recently built offshore wind farm in the Netherlands (2021) has a water depth ranging from 15 to 40 meters. Other examples in the Baltic Sea:

- Wind farm Arcadis Ost 1 in Germany will be built in 2022 with monopiles at water depths of approximately 43 meters.
- Wind farm Karehamn in Sweden is built with gravity-based structures at water depths of approximately 21 meters.

Wind farm site Estonia 2

The water depth in wind farm site Estonia 2 ranges from approximately 27 to 38 meters. Especially the north side is shallower compared to the south. Approximately 20 percent of the wind farm site has a water depth between 27 and 30 meters. The other 85 percent is between 30 and 38 meters. This range is comparable to wind farm site Estonia 1.

Wind farm site Latvia 1

The water depth in wind farm site Latvia 1 ranges from approximately 17 to 30 meters in the north-eastern part of the wind farm site and approximately 30 to 43 meters in the south-western part. When looking at more detailed nautical maps, the water depth at in Latvia 1 is approximately 29 to 38 meters[4]. This range of water depth is comparable to wind farm site Estonia 1 and 2.

Wind farm site Latvia 2

The eastern part of the wind farm site (approximately 60 percent) has a water depth range between 17 to 45 meters. Further from the coast, the water depth steadily increases. In this part of the wind farm site a wide range of foundations options are feasible and cost-effective.

However, the western part of the wind farm site (approximately 40 percent) ranges between 45 to 75 meters. When looking at more detailed nautical maps, the water depth at this deeper western part does not exceed 60 meters[5]. In these conditions the foundations options are more limited, and additional costs and complexity could be significant.

4.2.4 Mitigating measures

In general, the water depth for the different wind farm sites is feasible. However, the depth of more than approximately 50 meters is a limitation of wind farm site Latvia 2. Possible mitigating measures are using alternative types of foundations, like jackets, or selecting floating offshore wind turbines. These measures have an influence on the business case of a wind farm.

4.2.5 Conclusion

The final scores for the criterium water depth are listed in Table 4.2. Wind farm sites Estonia 1, 2 and Latvia 1 are given 8 points. The average water depth is common for offshore wind farm developments. However, a shallower water depth (< 20 meters) would give lower costs. 5 Points are given to wind farm site Latvia 2, because 40 percent of the site has a significant deeper water depth, limiting the foundations options and increasing the development costs for offshore wind energy.

Table 4.2 Scores water depth (criterium weight = 5%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	8	8	8	5

[4] http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=The+Strait+of+Irbe+and+to+the+Port+of+Ventspils+boating+app#9.36/56.9962/20.8890
[5] http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=The+Strait+of+Irbe+and+to+the+Port+of+Ventspils+boating+app#9.36/56.9962/20.8890

4.3 Waves and currents

4.3.1 Introduction and methodology

A wind turbine and its foundation need to withstand extreme weather conditions, like strong currents and large waves. Engineers designing wind turbines use models to understand how different loads, like waves and currents, will impact a wind turbine and its foundation. Moreover, strong currents and extreme waves make it harder to access turbines, especially for unplanned service activities in bad weather, adding cost and reducing energy production.

Waves and currents are not relevant for the grid connection during the operational phase, because the grid is placed on or buried in the seabed. The construction of the grid connection can take place outside of the storm season or extreme weather conditions.

Assessment framework and scores

Each wind farm site will be provided a score based on the velocity of the currents and the wave height. Wind farm sites with extreme currents and waves will be given a low score. Wind farm sites normal currents and waves will be given a high score.

4.3.2 Data overview and description

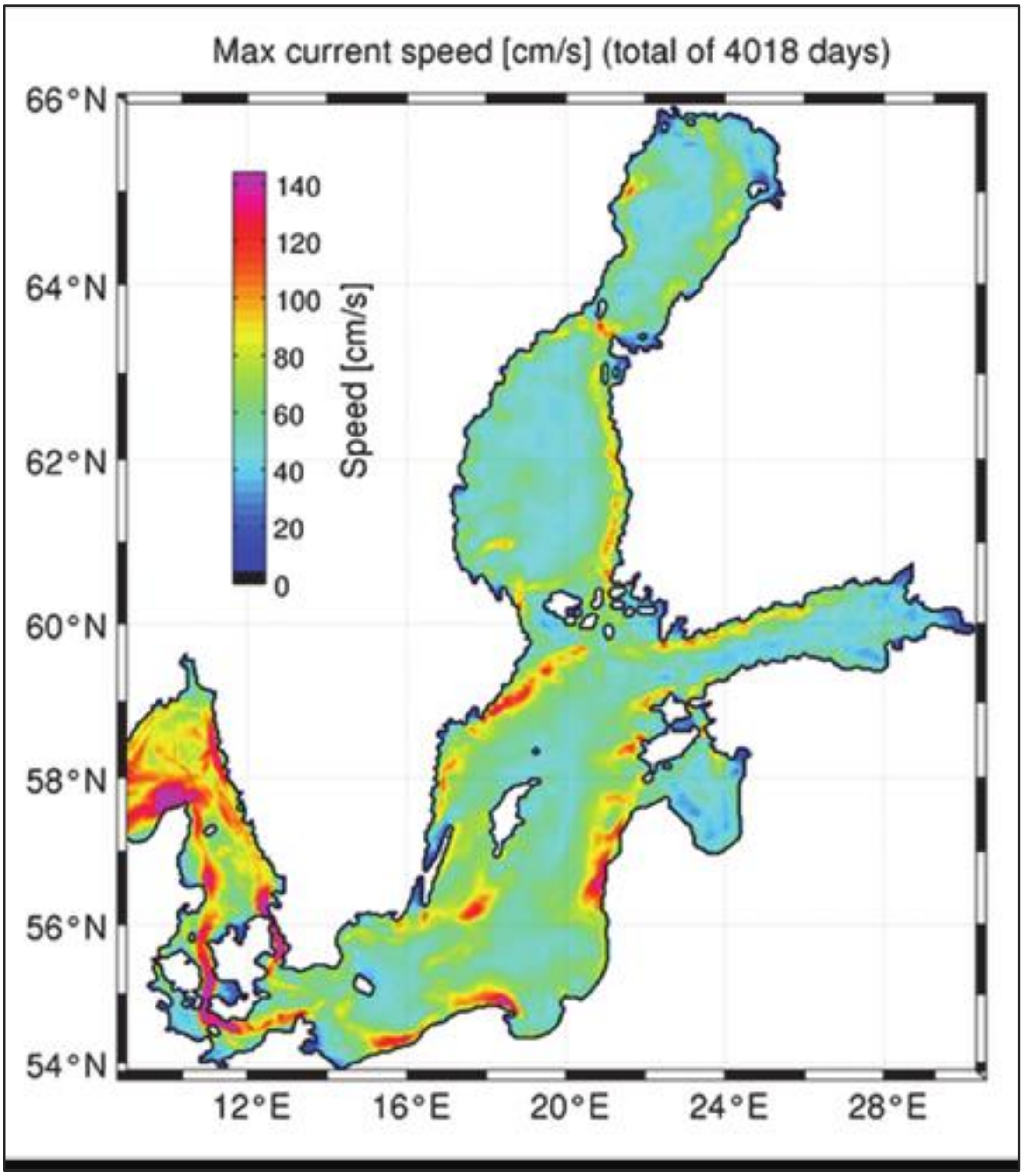
Currents

Currents in the Baltic Sea are generally weak. Current velocity increases with the height above the seabed, being zero at the seabed and maximum at the top of the layer. The 30-year mean values of the surface current velocity of large areas of the Baltic Sea is between 0 and 0,03 m/s. Maxima of up to almost 0,28 m/s appear in the Kattegat, values of up to 0,17 m/s and 0,13 m/s in the Øresund and Great Belt, respectively, and there are several channel-like regions throughout the whole Baltic Sea with enhanced current velocities of about 0,05–0,08 m/s on average[6].

Maximum velocity values are expected to appear during storm events. Figure 4.7 shows the maximum current velocity in the Baltic Sea derived from a hydrodynamic ocean circulation model of the Baltic Sea[7]. The maximum currents velocity is mostly ranging from 0.4 – 0.8 m/s, reaching higher values of up to 1.4 m/s only in some smaller areas.

[6] Placke et al., (2018) Long-Term Mean Circulation of the Baltic Sea as Represented by Various Ocean Circulation Models
[7] Suchandt et al., (2014) Analysis of ocean surface currents with TanDEM-X ATI: A case study in the Baltic Sea

Figure 4.7 Maximum current velocity in the Baltic Sea



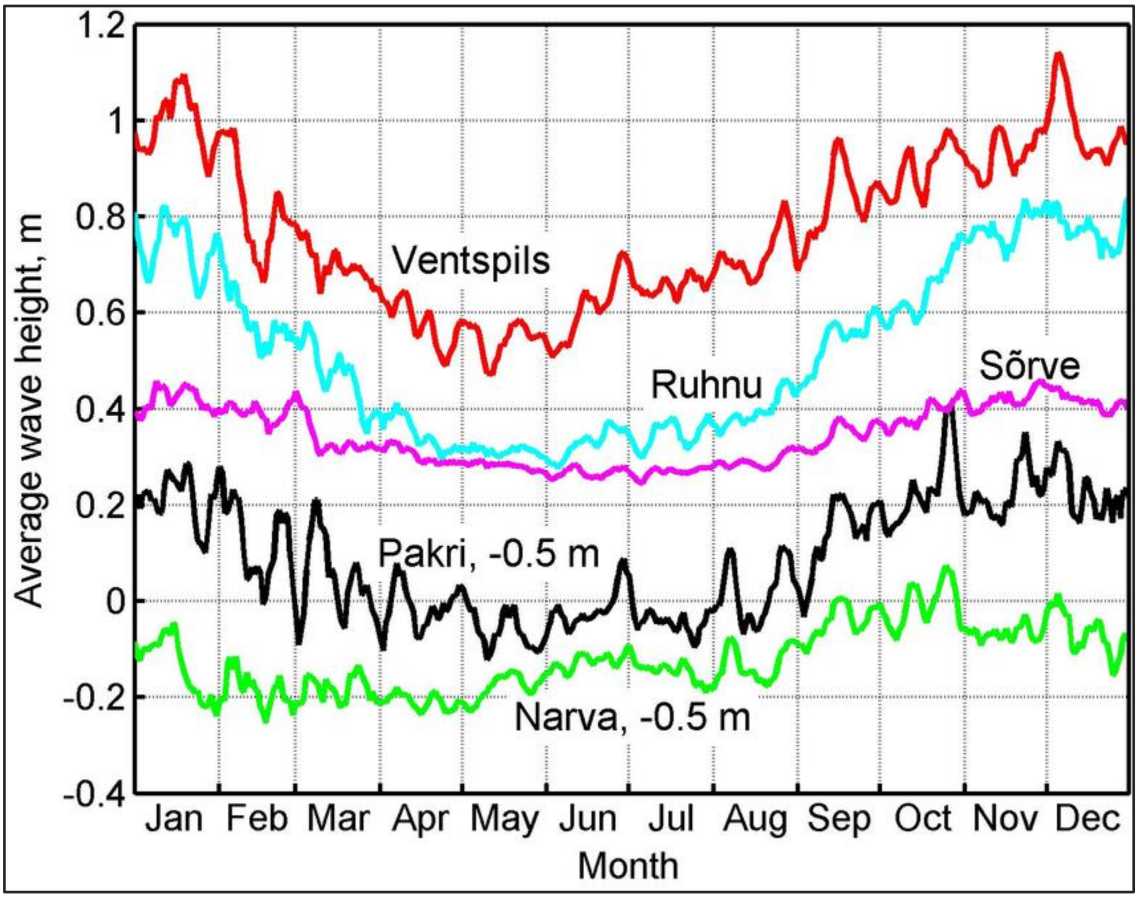
Source: Suchandt et al. (2014)

Waves

The long-term average wave heights in the Gulf of Riga are relatively low. Figure 4.8 shows the seasonal variation over the average wave height, observed between 1954 and 2011. Ventspils is nearby wind farm site Latvia 2, Ruhnu is nearby Estonia 2 and Latvia 1 and Sõrve is nearby Estonia 1. The long-term average wave height is approximately 0,8 m in Ventspils, 0.6 m at Ruhnu and 0.4 m at Sõrve.

The maximum height near Sõrve and Ruhnu. does not exceed 3 meters.

Figure 4.8 Seasonal variation of average wave height in meters



Source: Eelsalu et al. (2014) Visually observed wave climate in the Gulf of Riga

4.3.3 Assessment of wind farm sites

Currents

The maximum current velocity in wind farm site Estonia 2 and Latvia 1 is very low: approximately 0,6 m/s. The maximum current velocity in wind farm site Estonia 1 and Latvia 2 are higher approximately 0,8 – 1,0 m/s. However, these current velocities are still considered relatively low for offshore wind farm developments. For example, several wind farms with multiple foundation options are already realised in areas in the Baltic Sea with higher current velocities compared to the 4 wind farm sites from this study. Examples are wind farm Lillgrund and Kriegersvlak. Therefore, these maximum currents velocities are causing no constraints. These current velocities can easily be considered in the design of the foundations.

Waves

The average wave heights near all wind farm sites are relatively low: approximately 0,4 – 0,8 meters. For example, the average wave height of wind farms in the Dutch North Sea are around 1- 1,30 meters with a maximum of 7,9 meters. Strong winds could result in 3–4 m high waves in the deepest part of the Gulf of Riga; prolonged storms may result in wave heights of 5–6 m[8].

[8] http://www.estonica.org/en/Nature/The_Baltic_Sea/The_Gulf_of_Riga/

The identified waves values are causing no constraints for the development of wind energy on these sites. These wave heights can be considered in the design of the foundations of the wind turbines.

Also, the common wave heights (and currents) in this region have no constraints during the construction phase. A construction ship for a foundation or wind turbine can work with wave heights up to 2 meters. Moreover, wind turbines are usually constructed using jack-up ships. Jack-up ships are more resistant to sea conditions due to their legs fixed into the seabed. Construction during storms with extreme waves and currents should however be avoided.

4.3.4 Mitigating measures

No mitigating measures are necessary. The maximum and average current and waves values can be considered in the design of the foundations of the wind turbines.

4.3.5 Conclusion

All wind farm sites are given the maximum scores for the criteria waves and currents. The impact of the identified waves and currents are very low and indifferent for the four wind farm sites.

Table 4.3 Scores waves and currents (criterium weight = 5%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	10	10	10	10

4.4 Soil conditions

4.4.1 Introduction and methodology

The soil conditions will have an impact on the design and construction of the wind turbine foundations and the grid connection.

Wind turbine foundations

On an international scale, monopiles are most frequently used for the foundations of offshore wind turbines. In the Baltic Sea however, most realised offshore wind farms are constructed on gravity-based structures (GBS) made of concrete (see paragraph 4.6).

GBS are positioned on top of the seabed. Therefore, the bearing capacity of the topsoil is very relevant to prevent sinking or slanting of the GBS. Weak seabed conditions, like muddy, clay soil, should be removed and more robust layers, like sand with stones, should be placed at the construction site. If a weak top layer is only a few meters thick, this activity does not have a significant impact on the development of wind energy or its business case. However, if the mud or clay layers extend to large depths up to 10 meters, a very deep and large area should be excavated and filled with more robust soil. This could have a large impact on the feasibility of wind energy with GBS. If this is the case, the usage of more innovative foundation options, like suctions buckets, could be a solution (see paragraph 4.6 for a further description).

Monopiles, jackets or tripods are normally piled into the soil. Assuming a 20 MW wind turbine with a tip height of 300 meters in an area with a water depth of approximately 25-45 meters, the support monopiles are piled into the soil up to approximately 30 or 50 meters. Therefore, the deeper soil conditions (below the seabed substrate) are very relevant for the construction of wind turbines with monopiles. Rocks and stone layers, like limestone or sandstone, should be avoided. Sandy layers are more suitable for pile driving. For the further development of offshore wind energy in the Baltic Sea, a geophysical survey needs to be executed to provide a better understanding of the soil conditions. Drilling monopiles could be an alternative in rock and stone layers, but this method is expected to be more complex and costly. Finally, the topsoil is also of importance. Deep top layers of mud or clay should be avoided, because in that case the piles should be longer (drilled or piled deeper into the seabed). Moreover, drilling is less feasible in areas with a muddy top layer. Mud or other soft soil creates additional complexity to clear the drilling holes.

Grid connection

Deeper soil conditions are not relevant for grid connection options, because the grid is constructed in the top layer of the seabed. The dynamics of the top layer of the seabed is however relevant for laying the grid connection cables. Especially migrating sand waves could have an impact, because a cable must be installed below the non-moving seabed. Detailed data on the presence of sand waves is not available for this study and modelling sand waves is not part of this study. However, we can assume that the dynamics of the seabed and the presence of sand waves are limited, because the currents are also limited. Helcom[9] has data on the average current velocity at the bottom of the Baltic Sea. The bottom current velocity at the 4 wind farm sites does not exceed an average of 0,04 m/s.

[9] Model results of the annual mean bottom current velocity (m/s).

Another relevant aspect for grid connection related to the soil conditions is the presence of different sediment types. If a grid route passes many different sediment types, this will have implications for the complexity of the construction and the usage of several types of equipment. Finally, the presence of clay, mud or fine sand have more isolation effects compared to coarse sand and could result in a reduced heat transfer from the cable to the surroundings. Heat transfer is important for proper functioning of electricity cables.

Assessment framework and scores

As mentioned above, weak seabed conditions in the top layers and deeper rock and stone layers should be avoided. Their presence could result in the exclusion of certain foundation options/methods or add additional complexity and costs to the wind farm project.

Therefore, each wind farm site will be given a score based on the presence and approximate depth of weak seabed conditions in the top layers and deeper stone and rock layers. Wind farm sites located in a zone with a high likelihood of weak seabed conditions in the top layers and deeper stone and rock layers will be given a low score. Wind farm sites located in a zone with a low likelihood of weak seabed conditions in the top layers and deeper stone and rock layers will be given a high score.

4.4.2 Data overview and description

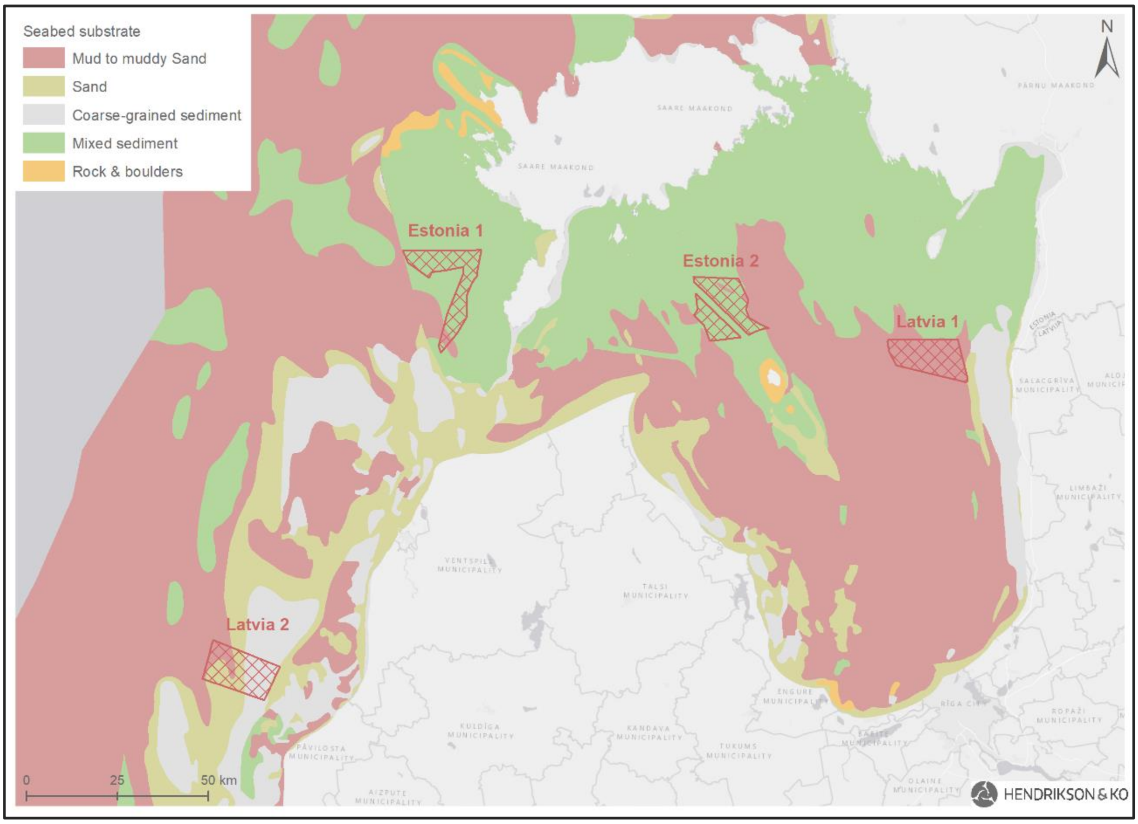
Seabed geology data was acquired from a public domain - European Marine Observation and Data Network (EMODnet Geology). Two maps were used to assess the soil conditions criteria. Firstly, the Seabed Substrate map at the scale of 1:1 000 000 and secondly Sea-floor Geology, Pre-Quaternary lithology map. A publication by the Geological Survey of Estonia[10] was used as complementary data.

Box 1. Latvian geology data

> Additional geology data was received from the Latvian Environment, Geology and Meteorology Centre (LVGMC). At this point, the geology data provided by the LVGMC, is not further used in this assessment.
> The main reason for not using the provided data is that it is unclear how the geological profiles are compiled due to the fact that the boreholes reaches only the top seabed layers and there is no information on how the rest of the data is gathered. Therefore, interpreting these maps might be misleading. Secondly, these maps are in Russian and Latvian and sometimes hard to read due to the visual quality of these quite old documents. Therefore, it is easy to misunderstand the information and give false results. Finally, wind farm site Latvia 2 is not covered by the maps provided by the LVGMC.

[10] Tulling et al. (2021) Ülevaade meregeoloogilisest andmestikust meretuuleparkide planeerimieks

Figure 4.9 Sediment types in the top layer of the seabed



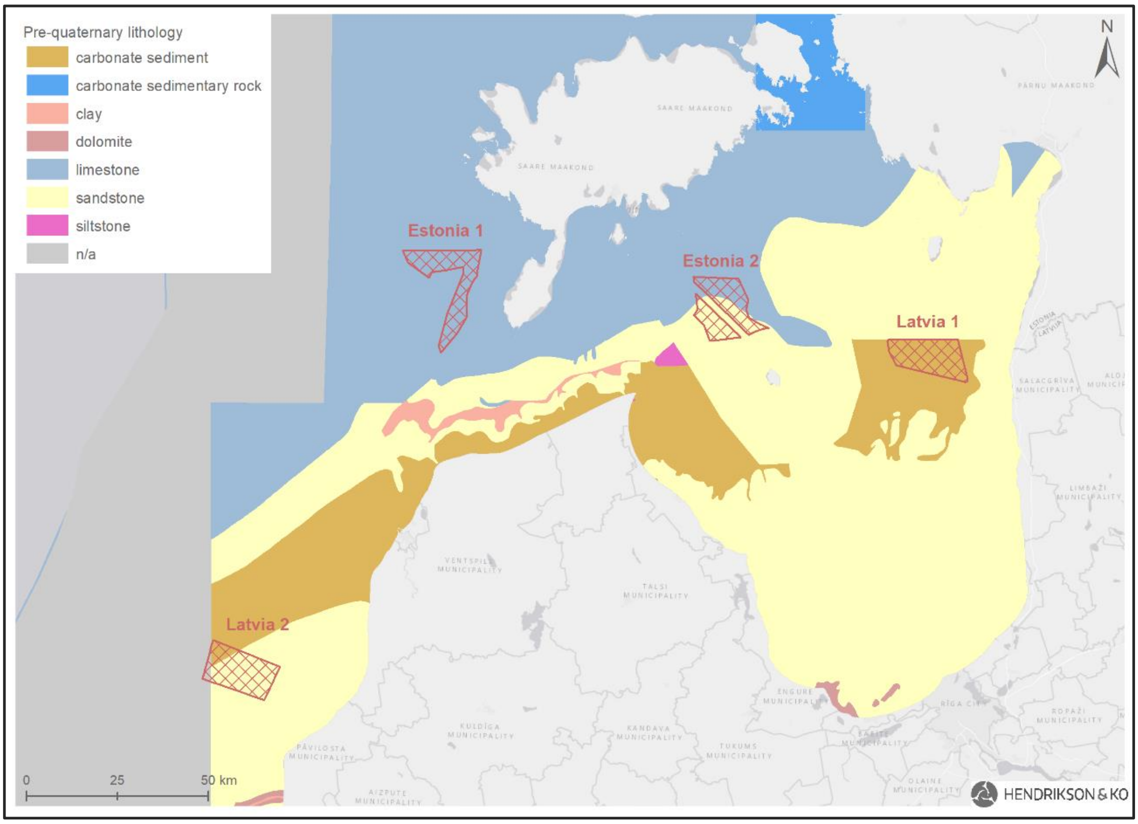
The Estonia 1 top layer of the seabed mainly consists of mixed sediment and a small area in the South corner can be identified as mud and muddy sand. According to the Geological Survey of Estonia publication Estonia 1 area is covered with thin to some places non-existent sediment layer <5 or 5-10 meters.

The Estonia 2 top layer of the seabed is also described as mixed sediment. According to the Geological Survey of Estonia publication, the Estonia 2 seabed sediment layer is quite thick at 25-30 meters.

The Latvia 1 top layer of the seabed consists of mud and muddy sand. Seabed substrate thickness is unknown but due to the similar geographical locations as wind farm site Estonia 2, it can be assumed that the seabed sediment thickness is relatively the same as for Estonia 2.

The Latvia 2 top layer of the seabed consists mainly of sand and coarse-grained sediment. Only in a small western part the top layer consists of mud to muddy sand. Seabed substrate thickness is unknown.

Figure 4.10 Pre-quaternary lithology



The bedrock from wind farm site Estonia 1 is made from limestone. Estonia 2 bedrock consist of limestone and sandstone. Most of the seabed substrate lays on sandstone, but the Northern part of the wind farm sites consists of limestone. Wind farm site Latvia 1 bedrock is made from carbonate sediment. Wind farm site Latvia 2 bedrock consists of carbonate sediment and sandstone. Most of the seabed substrate lays on sandstone, but the North-West part of the wind farm site consists of carbonate sediment.

4.4.3 Assessment of wind farm sites

Wind farm site Estonia 1

The top layer of the seabed in wind farm site Estonia 1 consists mainly of mixed sediment (see Figure 4.9). The following sediment types could be part of this mixed sediment: clay, mud, till (glacial sediment consisting of sand, gravel, as well as rocks) and diamiction (particles ranging in size from clay to rocks, suspended in a matrix of mud or sand). Deeper below the seabed there is a limestone plateau (see Figure 4.10). According to the Estonian Geology report[11] the limestone plateau is present from approximately 5 to 10 meters under the seabed. This limestone plateau could impact the feasibility of using foundations options like monopiles, jackets, tripods, and suctions buckets. To conclude, the possible weak seabed conditions (mud, clay) in combination with possible rocks in the top sediment layer and the limestone plateau underneath could have a strong impact on the development of wind energy on this site.

[11] Tuuling, S.Suuroja, A.Veski, M.Liira, (2021). Ülevaade meregeoloogilisest andmestikust meretuuleparkide planeerimiseks. Eesti Geoloogiateenistus.

Wind farm site Estonia 2

The top layer of the seabed in wind farm site Estonia 2 consists mainly of mixed sediment (see Figure 4.9). The following sediment types could be part of this mixed sediment: clay, mud, till (glacial sediment consisting of sand, gravel, as well as rocks) and diamiction (particles ranging in size from clay to rocks, suspended in a matrix of mud or sand). Deeper below the seabed there is a limestone and sandstone plateau (see Figure 4.10). According to the Estonian Geology report the limestone and sandstone plateau is present from approximately 20 to 25 meters under the seabed. Monopiles are normally piled into the seabed for up to 30 meters. Because of the high depth of this limestone and sandstone plateau, this probably does not impact other foundation options like jackets, tripods, GBS and suction buckets. To conclude, the possible weak seabed conditions (mud, clay) in combination with possible rocks in the top sediment layer and the limestone and sandstone plateau underneath could have a strong impact on the development of wind energy on this site.

Wind farm site Latvia 1

The top layer of the seabed in wind farm site Latvia 1 consists of mud to muddy sand (see Figure 4.9). Deeper below the seabed there is a carbonate sediment layer (see Figure 4.10). Carbonate sediment can consist of clay, limestone, dolomite stone, gypsum. The depth of the carbonate layer is not known. Due to the similar geographical locations with wind farm site Estonia 2, it can be expected that also in Latvia 1 limestone and sandstone plateaus are present from approximately 20 to 25 meters under the seabed. To conclude, the muddy top layer of the seabed and possible stone layer underneath could have a strong impact on the development of wind energy on this site.

Wind farm site Latvia 2

The top layer of the seabed in wind farm site Latvia 2 consists mainly of sand and coarse-grained sediment (see Figure 4.9). Deeper below the seabed there is a sandstone and carbonate sediment layer (see Figure 4.10). Carbonate sediment can consist of clay, limestone, dolomite stone, gypsum. The depth of the sandstone and carbonate layers is not known. To conclude, the sandstone and carbonate sediment layer underneath the top layer of the seabed could have a strong impact on the development of wind energy on this site.

4.4.4 Mitigating measures

For the further development of offshore wind energy, a geophysical survey needs to be executed to provide a better understanding of the seabed and deeper soil conditions. Especially the depth of possible stone formations under the top layer of the seabed in Latvia should be identified. If geophysical surveys confirm the presence of rock and stone formations in deep layers under the seabed, a good mitigating measure is the usage of gravity-based foundations or other methods that does not include pile driving, like drilling.

Also, the carrying capacity of the seabed should be better identified given the presence of softer mud and clay in the top layers of the seabed. If the mud or clay layers extend to large depths up to 10 meters, a solution could be the usage of suction buckets (see paragraph 4.6). Suctions buckets are better able to cope with weak topsoil conditions compared to GBS.

4.4.5 Conclusion

The top seabed layer for all four wind farm sites does not include main rock and boulders soils. However, weak seabed conditions (mud, clay) is expected in the top seabed layers of wind farm sites Estonia 1, 2 and Latvia 1. The weakest top layer with mud is expected in Latvia 1. Therefore, Latvia 1 is given a lower score. The top layer of Latvia 2 consists mainly of sand and coarse-grained sediment. Therefore, Latvia 2 is given a higher score.

Deeper below the seabed, all four wind farm sites have layers of limestone, sandstone, or carbonate sediment (including possible stone layers). The exact depth and consistency of these layers are unknown, especially on the Latvian side. In Estonia 1, the limestone plateau is relatively shallow compared to the sandstone and limestone plateau underneath Estonia 2, limiting the foundation options and methods. Therefore, Estonia 1 is given a somewhat lower score compared to Estonia 2.

The possible weak top seabed layers and the deeper stone layers could have a strong impact on the development of wind energy in all four wind farm sites. A geophysical survey needs to be executed to provide a better understanding of the location specific soil conditions.

Table 4.4 Scores soil conditions (criterium weight = 7%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	4	5	3	6

4.5 Wind speed & capacity factor

4.5.1 Introduction and methodology

Energy production is an important aspect to determine the feasibility of offshore wind farms. In this section, an energy yield assessment will give a good indication of the expected annual energy production of the wind farm areas. Below, there is a short description of the data, assumptions, and methodology that are used. The result is an expected annual energy yield for each of the four wind farm sites. This also includes the expected changes in energy production regarding climate change in time steps of 10 years.

Wind turbine technology

Which wind turbine technology we assume to be installed at the wind farm areas in Estonia and Latvia is related to the timeline of the development and the status of turbine types that are currently available or under development. For the past decade, the trend is a growing capacity of (offshore) wind turbines. The first 12 MW turbine by GE was built at the Maasvlakte in the Netherlands in 2019 (currently this model can produce up to 14MW) for certification and Vestas has already announced the V236 which has a rated capacity of 15 MW.

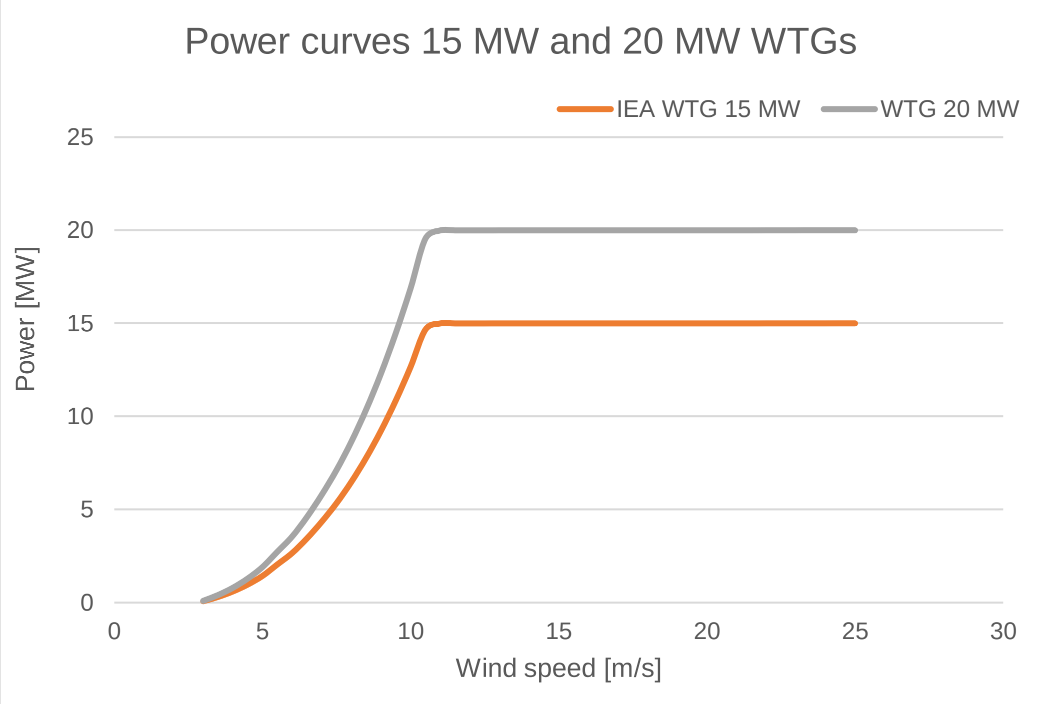
The construction of wind farms in Estonia and Latvia is expected to be around 2030. It is expected that the capacity of commercially available wind turbines has increased by then. It is worthwhile to explore the future wind turbine generation. Manufacturers and researchers are known to be working on wind turbine designs with more than 12 MW rated capacity. In 2017 an EU Research Project on 10-20 MW turbines has been finalized (INNWIND.EU[12]) and in Germany and Denmark, plans are made to establish test centres of 15 to 20 MW nacelles[13,14].

This study assumes that wind turbines with a rated capacity of 20 MW will be available by the end of this decade. The parameters of the 20 MW wind turbine, relevant for this report, are based on a 15 MW offshore wind turbine reference design by the IEA, as launched by the US National Renewable Energy Laboratory (NREL)[15].

A key input for the energy yield is the power curve, listing the power generated at wind speeds between cut-in wind speed (the wind speed at which the wind turbine becomes operational) and the cut-out wind speed (the wind speed at which the wind turbine is switched off). Power curves can vary depending on the wind turbine design. As wind turbines in the range of 20 MW are not yet existent, assumptions on the power curve must made. The power curve is based on the IEA 15 MW offshore wind turbine reference design, being a valid benchmark for newer generations of wind turbines. The used power curves are shown in Figure 4.11.

[12] www.innwind.eu
[13] Lee, A. (2020). Germany plans testing for 20 MW wind turbines in new supersize signal. Recharge News, 17 February 2020.
[14] Foxwell, A. (2019). Test centre sets its sights on massive turbines, energy storage and conversion. Riviera, 29 October 2019.
[15] Gaertner, Evan et al. (2020). Definition of the IEA 15-Megawatt Offshore Reference Wind. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-75698. https://www.nrel.gov/docs/fy20osti/75698.pdf

Figure 4.11 Power curves of the IEA 15 MW reference turbine and the extrapolated 20 MW turbine used in this study



The key parameters of the reference turbine and the future wind turbine are described in Table 4.5. The rotor diameter is deducted from the ratio between swept area and rated capacity of the IEA 15 MW turbine. The lowest point of the rotor (27.5 m) is comparable to the reference turbine (30 m) and defines the hub height.

Table 4.5 Key parameters for IEA 15 MW reference wind turbine and 20 MW future wind turbine

Parameter	IEA 15 MW	Future 20 MW	Comment
Capacity	15 MW	20 MW	Capacity of the future wind turbine is based on expert judgement
Rotor diameter	240 m	275 m	Based on available wind turbines and IEA 15 MW reference turbine
Hub height	150 m	165 m	Based on available wind turbines and EIA 15 MW reference wind turbine

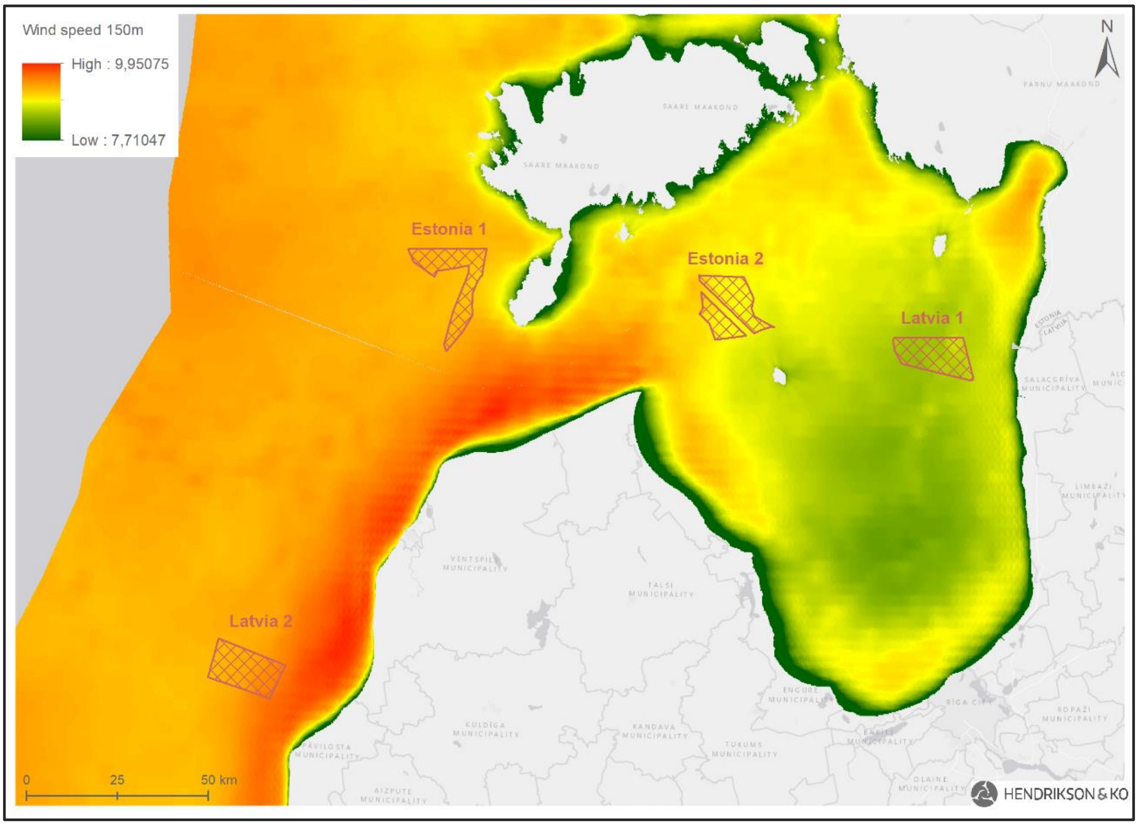
Wind climate

The purpose of determining the wind climate is to estimate the future energy production of the offshore wind farms. Generally, an Energy Yield Assessment (EYA) based on local measurement data from a met mast or LiDAR device is most accurate with the lowest uncertainty. Because there is no local measurement data available (yet), the online data source Global Wind Atlas (GWA) is used[16], see Figure 4.12. The GWA is based on the ERA5 dataset from ECMWF in the period between 2008-2017. This period is relatively short, considering a longer period could change the long-term wind climate slightly. Using WAsP[17] software of DTU the generalized wind climate is downscaled to a local wind

[16] https://globalwindatlas.info/
[17] https://www.wasp.dk/

climate every 250 m at different heights (10 m, 50 m, 100 m, 150 m, 200 m). Since the purpose of the EYA in this study is to compare different offshore wind areas, the modelled GWA wind climate is sufficient. In a later stadium of development, measurement data is advised for a more thorough analysis of the wind climate.

Figure 4.12 Global Wind Atlas (GWA) data for the wind farm sites



Energy Yield Assessment

To convert general wind climate created by the GWA the software package WindPRO (version 3.5) by EMD is used. This is industry-standard software for wind data analysis, layout determination, geographic modelling, and energy yield determination. For each wind farm site, an initial park design was created to obtain maximum yield regarding a minimal distance between wind turbines of five times the rotor diameter. The input in Table 4.6 and Table 4.7 is used for the energy yield modelling.

Table 4.6 Model assumptions

Model assumptions	
Elevation Grid	NASADEM (40x40km)
Roughness grid	Corine Land Cover 2018 (100m grid)
Wind data source	Global Wind Atlas (ERA5)
Neighbouring wind turbines	None
Wake decay constant	0.050 (default offshore)

Table 4.7 Assumptions per wind farm site

Assumptions per wind farm layout	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Number of WTGs	112	108	105	111
WTG type	RD275HH165-20,000	RD275HH165-20,000	RD275HH165-20,000	RD275HH165-20,000
Wind farm rated power [MW]	2240	2160	2100	2220
Rotor diameter [m]	275	275	275	275
Hub height [m]	165	165	165	165
Air density [kg/m3]	1.242	1.242	1.245	1.240

For each wind farm site, an approach was used where the maximum number of turbines was placed in the available area. This method is suitable for the purpose of assessing the relative energy yields of each wind farm site. However, the actual layouts may be significantly different. Moreover, the number of wind turbines per wind farm differs due to different sizes and shapes of the wind farm sites. A site with more turbines would of course generate more energy. In the assessment we take this into account. The final scores are based on energy yield per turbine.

Energy losses due to wake effect, maintenance and other causes are displayed in the table below.

Table 4.8 Annual energy losses per wind farm

	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Group 1: Wake effects				
Wake effects (all WTGs)	9.88%	11.23%	12.48%	12.30%
Blockage effect	1.50%	2.00%	2.00%	2.00%
Group 2: Availability				
Non-availability	5.00%	5.00%	5.00%	5.00%
Balance of plant	0.10%	0.10%	0.10%	0.10%
Grid	0.10%	0.10%	0.10%	0.10%
Group 3: Turbine performance				
Power curve	2.00%	2.00%	2.00%	2.00%
High wind hysteresis	0.50%	0.50%	0.50%	0.50%
Wind flow	1.00%	1.00%	1.00%	1.00%
Group 4: Electrical				
Cable and transformation losses	2.00%	2.00%	2.00%	2.00%
Own electricity consumption	0.10%	0.10%	0.10%	0.10%
Group 5: Environmental				
Blade degradation due to icing	4.00%	4.00%	4.00%	4.00%
Blade degradation due to contamination	0.50%	0.50%	0.50%	0.50%

	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Shutdown due to icing, lightning, hail etc	0.30%	0.30%	0.30%	0.30%
High and low temperature	0%	0%	0%	0%
Group 6: Curtailment				
Wind sector management	0%	0%	0%	0%
Grid curtailment	0%	0%	0%	0%
Power purchase agreement	0%	0%	0%	0%
Noise	0%	0%	0%	0%
Shadow flicker	0%	0%	0%	0%
Birds	0%	0%	0%	0%
Bats	0%	0%	0%	0%

Climate Change

Climate change can have impact on weather and flow patterns in the atmosphere. While scientists agree that the average temperature around the world will increase, it is much harder to make assumptions or forecasts for specific areas. If this analysis were possible, the inaccuracies and uncertainties increase quickly when discussing weather patterns further and further ahead in time.

Tobin et al. (2016)[18] did a study on climate change impacts on the power generation of European wind farms in 2050. It turns out that climate change does not significantly (or poorly) change the power generation of European wind farms compared to intra-daily to interannual time scales. That does not mean there is no change, specifically for the Baltic, an increase in power generation is foreseen in climate change scenario RCP4.5[19] of 1% and in RCP8.5 the increase is 2% by 2050.

To show the impact of the upper case, this report considers a 2% increase by 2050 in wind power generation. It is assumed that the wind climate changes linear between now and 2050. This means 2030 has an increase of 0.66% and 2040 an increase of 1.33% in wind power generation in the Baltic. It must be noted that the uncertainties are likely to be higher than the expected changes in power generation.

4.5.2 Assessment of wind farm sites

In this section the results of the EYA are given per wind farm area. The gross energy yield does not consider any losses while the PARK energy yield considers the expected wake effects within the wind farm. The P50 energy yield (or net Annual Energy Production (AEP)) considers all losses as indicated in Figure 4.13.

[18] Isabelle Tobin et al. (2016). Climate change impacts on the power generation potential of a European mid-century wind farms scenario. Environmental Research Letters 11 (2016) 034013. doi:10.1088/1748-9326/11/3/034013
[19] A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by the IPCC. RCP4.5 is considered the intermediate scenario; RCP8.5 is considered the worst-case scenario.

Wind farm site Estonia 1

Figure 4.13 shows the initial wind farm layout of Estonia 1 consisting of 112 wind turbines. Table 4.9 contains the results of the analysis with a net AEP of 9.0 TWh per year.

Figure 4.13 Initial wind farm layout of area Estonia 1. The blue dots indicate a wind turbine.

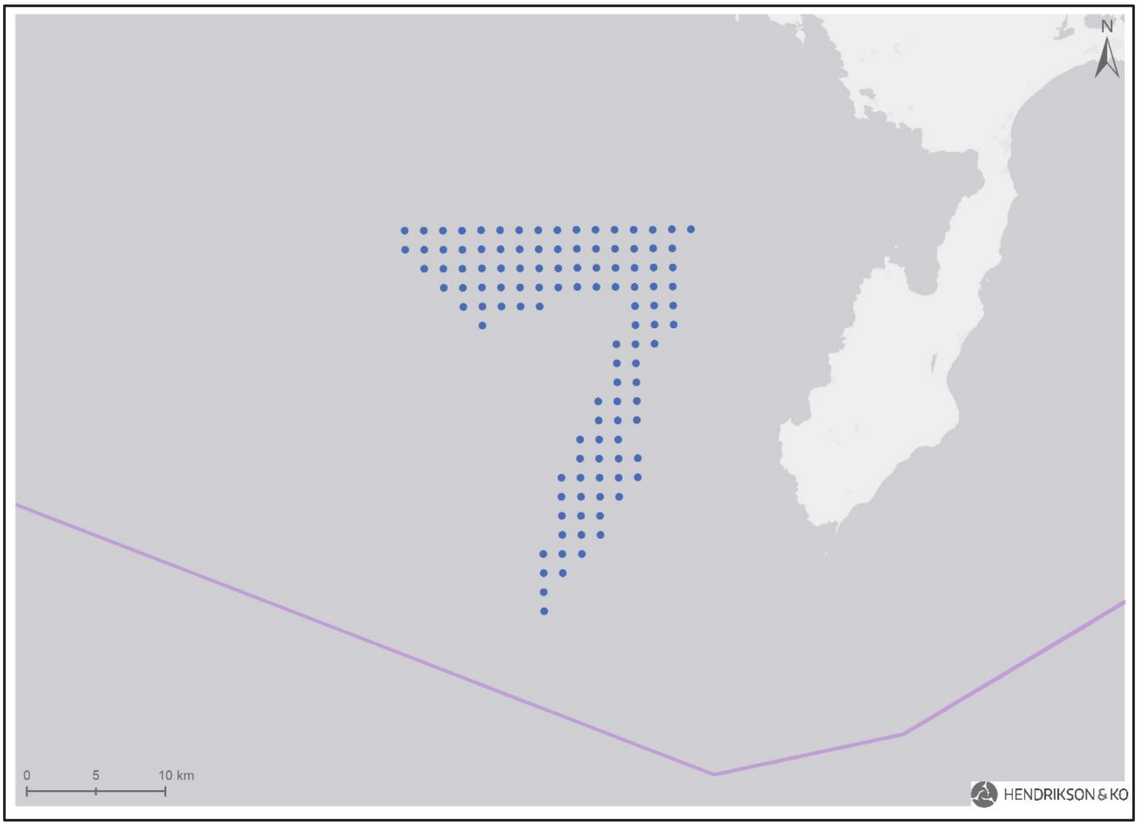


Table 4.9 Energy yield of Estonia 1

General output	Estonia 1
Wind speed at hub height [m/s]	9.7
Gross AEP [TWh/yr]	11.7
PARK AEP [TWh/yr]	10.6
Total losses [%]	24.2%
- Wake losses [%]	11.2%
- Other losses [%]	14.7%
P50	
Net AEP [TWh/yr]	9.0
Full load hours [h/yr]	4,000

The results above are representative for present day energy yield predictions. As indicated climate change can cause a change in wind speed. Based on Tobin et al. (2016) there is an estimation of the energy yield in time steps of 10 year taking climate change into account. The result can be seen in Table 4.10. It must be noted that the uncertainties are likely to be higher than the expected changes in power generation.

Table 4.10 Estimated change in annual energy production of Estonia 1 due to climate change

	Present day	2030	2040	2050
Net AEP [TWh/yr]	9.0	9.1	9.1	9.2

Wind farm site Estonia 2

Figure 4.14 shows the initial wind farm layout of Estonia 2 consisting of 108 wind turbines. Table 4.11 contains the results of the analysis with a net AEP of 8.6 TWh per year.

Figure 4.14 Initial wind farm layout of area Estonia 2. The blue dots indicate a wind turbine.

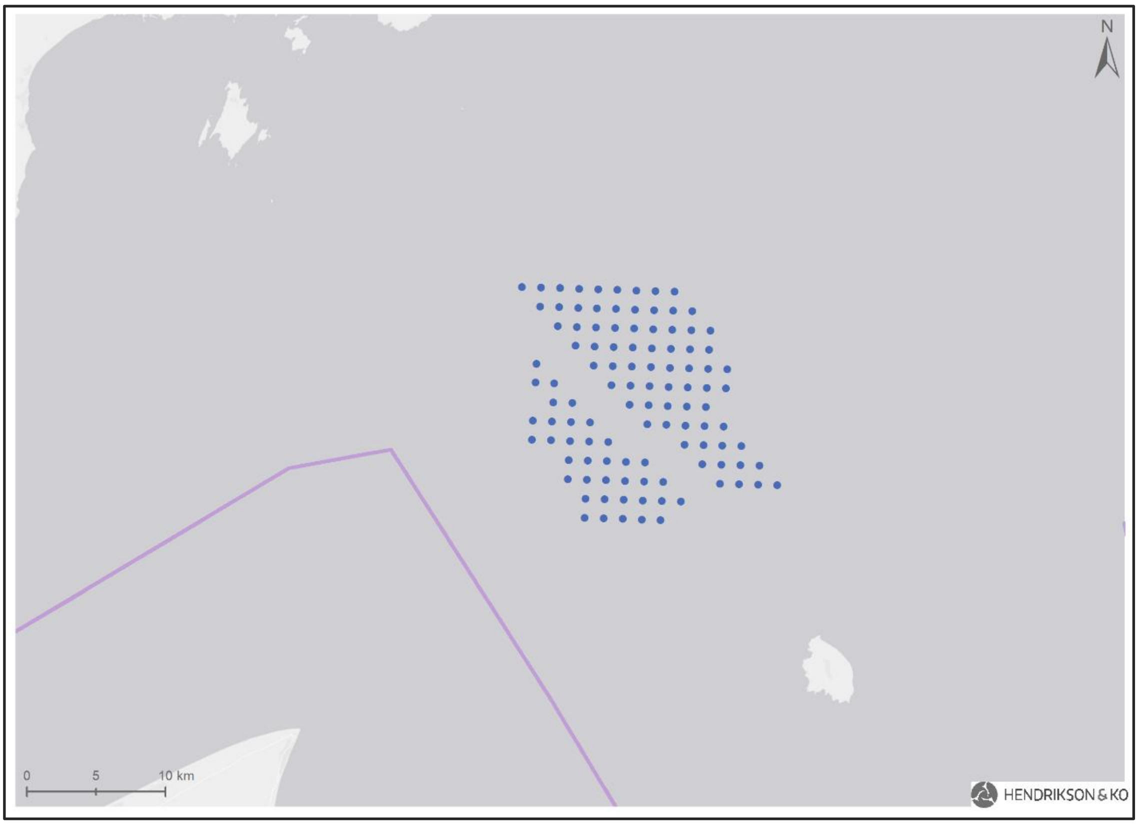


Table 4.11 Energy yield of Estonia 2

General output	Estonia 2
Wind speed at hub height [m/s]	9.6
Gross AEP [TWh/yr]	11.3
PARK AEP [TWh/yr]	10.0
Total losses [%]	25.8%
- Wake losses [%]	13.0%
- Other losses [%]	14.7%
P50	
Net AEP [TWh/yr]	8.6
Full load hours [h/yr]	4.000

The results above are representative for present day energy yield predictions. As indicated, climate change can cause a change in wind speed. Based on Tobin et al. (2016) there is an estimation of the energy yield in time steps of 10 year taking climate change into account. The result can be seen in Table 4.12. It must be noted that the uncertainties are likely to be higher than the expected changes in power generation.

Table 4.12 Estimated change in annual energy production of Estonia 2 due to climate change

	Present day	2030	2040	2050
Net AEP [TWh/yr]	8.6	8.7	8.7	8.8

Wind farm site Latvia 1

Figure 4.15 shows the initial wind farm layout of Latvia 1 consisting of 105 wind turbines. Table 4.13 contains the results of the analysis with a net AEP of 8.0 TWh per year.

Figure 4.15 Initial wind farm layout of area Latvia 1. The blue dots indicate a wind turbine.

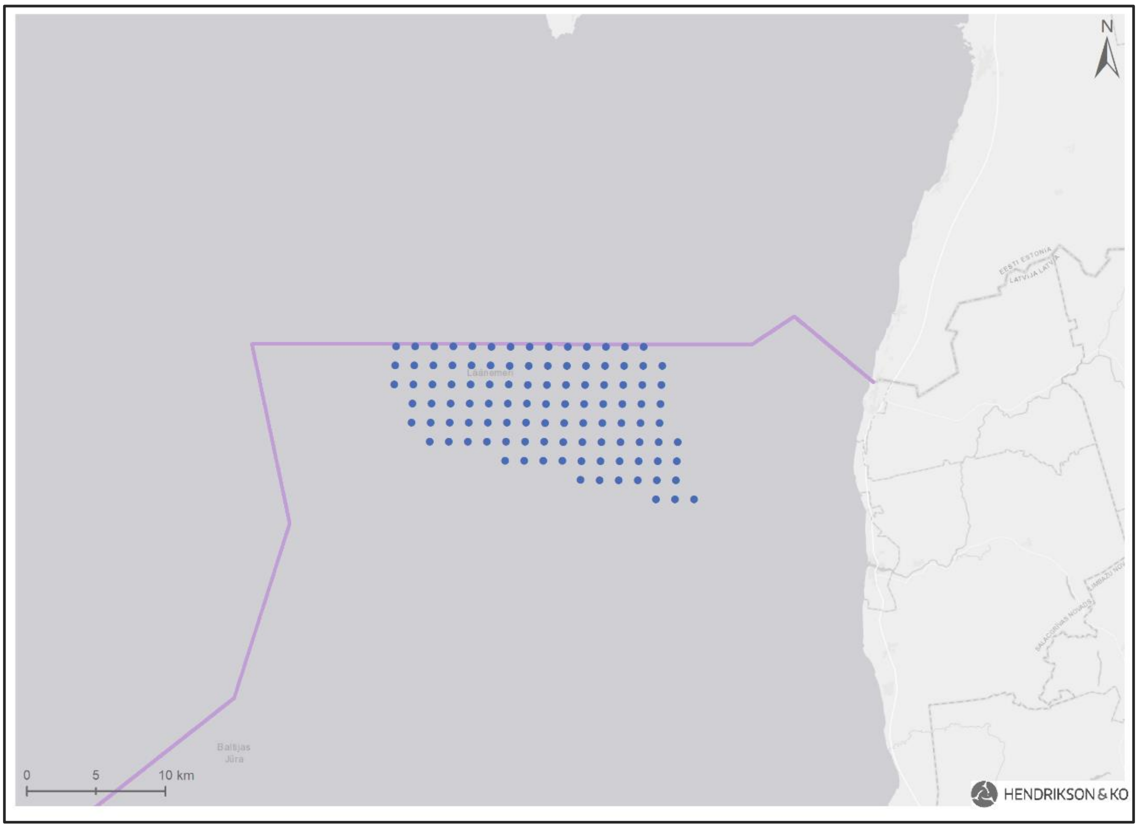


Table 4.13 Energy yield of Latvia 1

General output	Latvia 1
Wind speed at hub height [m/s]	9.5
Gross AEP [TWh/yr]	10.8
PARK AEP [TWh/yr]	9.4
Total losses [%]	26.8%
- Wake losses [%]	14.2%

General output	Latvia 1
- Other losses [%]	14.7%
P50	
Net AEP [TWh/yr]	8.0
Full load hours [h/yr]	3,800

The results above are representative for present day energy yield predictions. As indicated climate change can cause a change in wind speed. Based on Tobin et al. (2016) there is an estimation of the energy yield in time steps of 10 year taking climate change into account. The result can be seen in Table 4.14. It must be noted that the uncertainties are likely to be higher than the expected changes in power generation.

Table 4.14 Estimated change in annual energy production of Latvia 1 due to climate change

	Present day	2030	2040	2050
Net AEP [TWh/yr]	8.0	8.1	8.1	8.2

Wind farm site Latvia 2

Figure 4.16 shows the initial wind farm layout of Latvia 1 consisting of 111 wind turbines. Table 4.15 contains the results of the analysis with a net AEP of 8.8 TWh per year.

Figure 4.16 Initial wind farm layout of area Latvia 2. The blue dots indicate a wind turbine.

Table 4.15 Energy yield of Latvia 2

General output	Latvia 2
Wind speed at hub height [m/s]	9.8
Gross AEP [TWh/yr]	11.8
PARK AEP [TWh/yr]	10.3
Total losses [%]	26.7%
- Wake losses [%]	14.1%
- Other losses [%]	14.7%
P50	
Net AEP [GWh/yr]	8.8
Full load hours [h/yr]	4,000

The results above are representative for present day energy yield predictions. As indicated climate change can cause a change in wind speed. Based on Tobin et al. (2016) there is an estimation of the energy yield in time steps of 10 year taking climate change into account. The result can be seen in Table 4.16. It must be noted that the uncertainties are likely to be higher than the expected changes in power generation.

Table 4.16 Estimated change in annual energy production of Latvia 2 due to climate change

	Present day	2030	2040	2050
Net AEP [TWh/yr]	8.8	8.9	8.9	9.0

4.5.3 Conclusion

Table 4.17 and Table 4.18 show the absolute and relative production of each wind farm site, and on a turbine level. The projected energy productions are in no way limiting the feasibility of the wind farm sites, which means the assessment scores are very high. The wind farm sites Estonia 1, Estonia 2 and Latvia 2 score the same (within their respective margins of error) and all receive a maximum score of 10. Latvia 1, while still producing enough energy to be feasible, does have a significantly lower output than the other three wind farm sites and therefore receives a lower score.

While Figure 4.12 shows a higher average wind speed for wind area site Latvia 2, the shape of the site results in more wake effects and slightly lower energy output in this model. This shows that the wind farm sites are very close in terms of raw wind power.

The final scores are based on the energy production per turbine, and not total energy yield.

Table 4.17 Total production and production per turbine, present day and 2050

Wind area site	Total (TWh/yr)		Per turbine (GWh/yr)		Full load hours
	Present day	2050	Present day	2050	
Estonia 1	9.0	9.2	80	82	4000
Estonia 2	8.6	8.8	80	81	4000
Latvia 1	8.0	8.2	76	78	3800
Latvia 2	8.8	9.0	79	81	4000

Table 4.18 Relative annual energy production

Wind area site	Present day		2050	
	Total	Per turbine	Total	Per turbine
Estonia 1	100%	100%	100%	100%
Estonia 2	95.6%	99.1%	95.7%	99.2%
Latvia 1	88.9%	94.8%	89.1%	95.1%
Latvia 2	97.8%	98.7%	97.8%	98.7%

Table 4.19 Scores wind speed and capacity factor (criterium weight = 9%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	10	10	8	10

4.6 Foundation options

4.6.1 Introduction

Support structures and foundations are key aspects for the development of offshore wind projects. As foundations represent approximately 35% of the total cost of an offshore wind project[20], it is essential that they receive special attention in this study. In this paragraph the most common foundation options are described, their key characteristics and their feasibility based on the location specific situation of the 4 wind farm sites.

Assessment framework and scores

In this paragraph the feasibility of the foundation options is assessed based on the location specific conditions of the four wind farm sites. Certain conditions can result in:

- Additional foundation design requirements (larger, stiffer, stronger)
- Additional construction complexity
- The exclusion of possible foundation types

This could have an impact on the costs and further development of wind turbines in the four wind farm sites. Moreover, the exclusion of possible foundation types provides a risk in this stage of wind farm developments, because very little is known and future research on site specific conditions can result in more restrictive conditions for foundation options.

Therefore, wind farm sites with limited restrictive conditions for foundation options result in a higher score. Wind farm sites with multiple restrictive conditions for foundation options result in a lower score.

4.6.2 Foundation options and characteristics

Below the most common foundation options are visualized. For most offshore wind farms, monopiles are used for the foundations of the wind turbines. Approximately 80 percent of offshore wind turbine foundations in Europe are realized with monopiles (see Figure 4.18).

[20] https://www.mdpi.com/2077-1312/7/3/64

Figure 4.17 Foundation types for offshore wind turbines, left to right: Monopile, Tripod, Jacket, Suction bucket, Gravity Based, Floating)

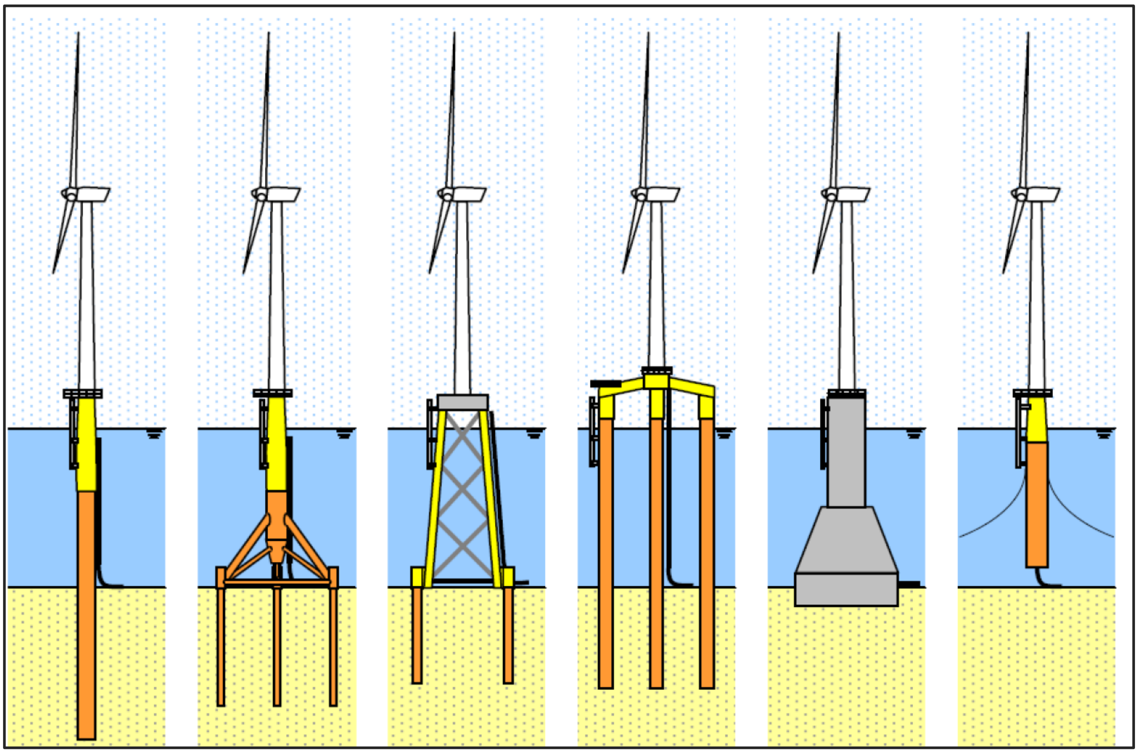
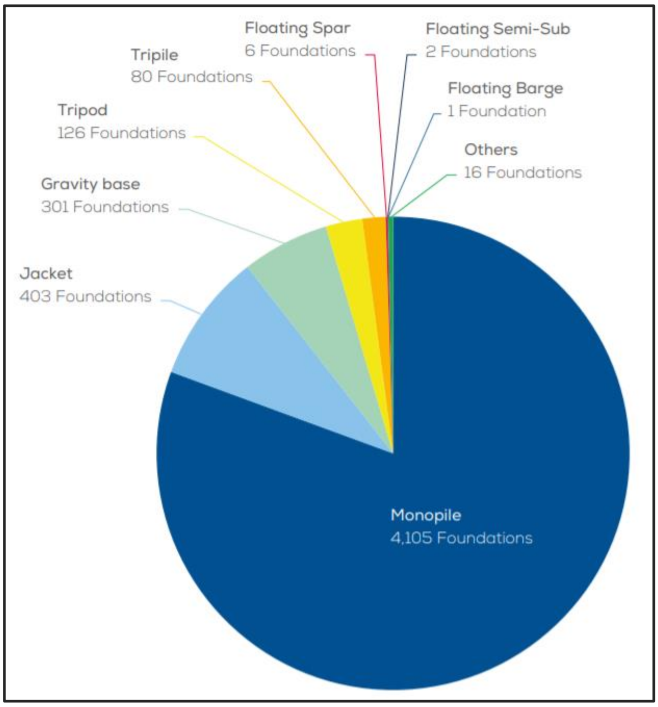


Figure 4.18 Share of foundation types for offshore wind turbines



Souce: Wind Europe 2019[21]

[21] Offshore Wind in Europe. Key Trends and statistics 2018 (2019). https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2018.pdf

Monopiles, Tripods and Jackets

Monopiles are quite simple structures, made up of a thick steel cylinder that is anchored directly into the seabed. They are buried under the seabed up to 30 to 40 meters to support a tower. Monopiles are installed more quickly compared to other options. Over the last few decades, offshore monopiles have become significantly larger to accommodate large offshore wind turbines (currently up to 260 meters in height) and are used in waters up to approximately 50 meters deep. A monopile carrying a 20 MW wind turbine located in an area with a water depth of 50 meters could have a diameter of approximately 15 meters, weigh 5000 tons and have a length of 120 meters. These kind of monopiles in these water depths could be piled into the soil up to approximately 50 meter below the seabed.

More complex support and foundation types are required at water depths below 50 metres. Jackets or tripods could be an alternative solution. These foundation types have multiple seabed anchoring points, which increases the levels of safety when anchoring the towers. Jackets and tripods are, however, more labour intensive to produce and more expensive compared to monopiles (approximately 20 percent).

Monopiles, tripods and jackets are usually fixed to the soil using pile driving or by drilling bore holes. The impact of the hydraulic pile driving hammer on top of the pile requires large and strong piles to prevent damage to the foundation. Pile driving through stone or rock layers should be avoided (see paragraph 4.4). Pile driving can have a negative effect on underwater life, like the harbour porpoise and seals (see paragraph 4.11 and 4.14). The stability of the piles in the seabed is ensured with scour protection to reduce local erosion around the foundation.

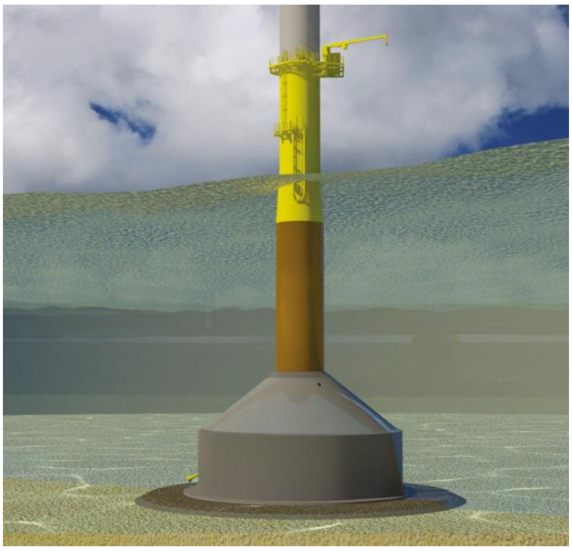
Ice conditions result in the requirement for larger and broader monopiles and therefore, could result in more costly or complex monopiles. This force of the moving ice plates depends on the size, the velocity and thickness of the ice plates (see paragraph 4.1).

Gravity based structures

Gravity-based support structures (GBS) are heavy structures (made from concrete) that are sunk and placed onto the seabed to provide support for offshore wind turbines. GBS is most used in the Baltic Sea. One of the reasons is that GBS are very viable in icing conditions, due to the stiffness, cone shape and weight of the concrete structures. Moreover, GBS is widely used in shallow waters, because deeper waters require very large and heavy GBS. Currently there are few wind farms in the Baltic Sea without a GBS; wind farm Kriegersvlak in Denmark is using monopiles.

GBS are mostly made from heavy concrete filled with ballast. A GBS foundation does not require pile driving. The seabed needs to be levelled and have enough bearing capacity. Weak seabed conditions, like mud, clay or silt should be removed and more robust sediment layers, like sand with stones should be placed at the construction site. Once this foundation is placed on the seabed, the interior hole is filled with ballast to achieve the final design weight to support the design loads.

Figure 4.19 Impressions of GBS



GBS are typically used for smaller wind turbines, in shallower waters and in areas that are prone to ice conditions. Large future wind turbines in deep waters might not be feasible with a GBS, because of the increased size and weight of the GBS that is required in these conditions. For example: an 80-meter high GBS to support a 20 MW wind turbine in an area with a water depth of 60 meters, weighs approximately 30.000 tons (14.000 tons of concrete plus another 17.000 tons of ballast). Current heavy lift vessels are not able to hoist structures with such weights.

A possible solution to deal with the weight of GBS without using heavy lift vessels, is to design and build self-floating GBS. A self-floating GBS uses large geometric volumes that result in the production of self-buoyant structures. Once ready, tugboats can be used to transport to the offshore site and no heavy-lift vessel is required. Once at the site, an injection of water sinks the structure to the seabed and a permanent ballast is then provided by sand.

Floating GBS could be built onshore (port or wharf) and rolled or slipped into the sea. It is also possible to create an offshore floating GBS construction site using sheet piling or dikes, whereupon the water is pumped out of the site. When the construction of the floating is GBS is finished, water can come in and the floating GBS is ready to be tugged towards the wind farm site. An example of this method is used for the Blyth Offshore Demonstrator Windfarm Project. This is the first project where floating GBS method has been successfully used for an offshore windfarm[22].

[22] https://www.bamnuttall.co.uk/case-study/blyth-offshore-demonstrator/

Figure 4.20 Blyth Offshore Demonstrator project – using floating GBS constructed in a dry dock

The main disadvantages of constructing/building (floating) GBS compared to normal monopiles are:

- Long construction times
- Large production facilities
- Labour intensive

Finally, the location of the production facility of floating GBS is of importance, since the floating GBS should be tugged to the project location.

Suction buckets

Another foundation option is the usage of suction buckets. The buckets are essentially placed on the seabed and the water will be pumped out of the buckets. The negative pressure results in a suction of the buckets into the seabed for several meters. To improve the stability of wind turbine foundations with suction buckets, multiple buckets could be used. Typical and proven examples used for wind turbines are jackets with 3 suction buckets and a monopile with 3 suctions buckets (tri-suction pile caisson). These foundations are effective in water depth up to 50 meters or more.

Suction buckets do not require pile driving and are better equipped to be used in more weak seabed conditions compared to GBS. Another advantage of suctions buckets is the viability in ice conditions. Structures with suction buckets are expected to be more expensive compared to conventional monopiles or GBS.

Figure 4.21 Impression 3 suctions buckets jacket (left) and tri-suction pile caisson (right)

Floating wind turbines

A rapidly developing option is floating wind turbines. Until recently, wind turbines were installed on fixed foundations. Therefore, they could not be installed in very deep or complex seabed locations, something that has changed with the advent of floating structures. Wind turbines can now be installed on these platforms, which are anchored to the seabed by means of flexible anchors, chains, or steel cables. It can be expected that floating wind energy in areas deeper than 50 meters will become cheaper than conventional wind turbines with fixed foundations if these are at all possible at these depths. Floating wind turbines are however still in development and will most likely become a mature and cost-effective solution in the next 5 to 10 years.

Finally, floating wind turbines are currently thought to be infeasible in areas with icing conditions. The anchoring is not expected to withstand the forces arising due to moving ice plates.

4.6.3 Assessment of wind farm sites

The feasibility of the described foundation options is based on the most important criteria: water depth, icing conditions and soil conditions. The identified waves and currents conditions for this project do not significantly impact the foundation options (see paragraph 4.3). Ecological effects of installing foundations are not included in this assessment (see paragraphs 4.11 - 4.15).

Ice conditions

Most offshore wind farms are built with steel monopiles fixed to the soil with pile driving. However, all wind farm sites are in areas with frequent ice conditions during the winter. Ice conditions result in the requirement for larger and broader monopiles and therefore, could result in more costly monopiles. This force of the moving ice plates depends on the size, the velocity and thickness of the ice plates (see paragraph 4.1). Moreover, the rhythmic forces of ice plates could result in horizontal swinging of the monopile. This frequency does not have an impact if the frequency does not resonate with the own frequency of the support structure. This should be examined further in the detailed design phase.

Generally, GBS, jackets, tripods, or suction buckets are more feasible with ice conditions. Especially GBS foundations are viable in icing conditions due to their stiffness, weight, and cone shape to break the ice plates. Jackets, tripods, and suctions buckets are normally considered to be more expensive compared to monopiles or GBS. Finally, floating wind energy structures are considered infeasible in areas with ice conditions.

Wind farm sites Estonia 1 and Latvia 2 are in areas with lower ice coverage and thickness compared to Estonia 2 and Latvia 1 (see 4.1).

Water depth

Deep waters require larger, stronger, and heavier foundations and therefore, higher construction complexity and costs. Conventional monopiles and GBS structures are considered infeasible at water depths above 30 meters. More innovative and expensive foundations options, like extra large monopiles, floating GBS, suction buckets, jackets and tripods are suitable for these conditions.

Wind farm sites Estonia 1, 2 and Latvia 1 have comparable water depths (see paragraph 4.2). Latvia 2 includes an area (approximately 40 percent of the total wind farm site) with a water depth above 45 meters and up to 60 meters.

Soil conditions

Finally, deeper soil conditions (below the seabed substrate) are very relevant for the construction of wind turbines with monopiles, jackets or tripods. Rocks and hard stone layers, like limestone or sandstone, should be avoided if possible. Deeper below the seabed, all four wind farm sites have possible layers of limestone, sandstone, or carbonate sediment (including possible stone layers). This means that driven pile monopiles might not be feasible. The usage of more innovative and expensive foundations options like floating GBS, jackets, suction buckets or other methods that does not include pile driving, like drilling, could be the best solution.

Especially for GBS, large top layers of weak soil (mud, clay, etc.) should be avoided (see paragraph 4.4). Also drilling methods are increasingly complex with weak top layers. Weak seabed conditions (mud, clay) are expected in the top seabed layers of wind farm sites Estonia 1, 2 and Latvia 1. The weakest top layer with mud is expected in Latvia 1. The top layer of Latvia 2 consists mainly of sand and coarse-grained sediment.

4.6.4 Conclusion

The above explained ice, water depth and soil conditions can result in:

- The necessity of designing larger, heavier, or stiffer foundation types (ice conditions and water depth)
- Additional construction complexity (removing large amounts of top layers for GBS or drilling monopiles because of stone formations)
- Or even the exclusion of certain foundation types (floating wind or small monopiles)

This could have an impact on the further development of wind turbines in the four wind farm sites. Some wind turbine foundation types can be excluded in specific areas, like conventional monopiles and GBS structures. However, more innovative, and complex foundation types and construction methods are still available for all four wind farm sites and their site-specific conditions. Floating GBS could be a viable foundation option given the ice conditions and water depths, but the feasibility highly depends on the bearing capacity of the top layer of the seabed. Suction buckets could be an alternative for GBS in areas with a relatively low bearing capacity. Large driven pile monopiles could also be a viable foundation option given the ice conditions and water depths, but the feasibility highly depends on the exact depth and strength of the deeper stone layers. Jackets with shorter piles or other construction methods that does not include pile driving, like drilling, could be an alternative. Finally, drilling is less feasible in areas with a muddy top layer, because it creates additional complexity to clear the drilling holes.

The scores for the criteria foundation options are displayed in Table 4.20. Estonia 1 and Latvia 2 is given the highest score. Estonia 1 has of a combination of relatively low ice conditions, low water depth, but a high likelihood of weak seabed layers. Latvia 2 has relatively low ice conditions, a low likelihood of weak seabed layers, but high water depths. Estonia 2 and Latvia 1 have high ice conditions, a high likelihood of weak seabed layers, but low water depths. Compared to Estonia 2, Latvia 1 has a higher likelihood of muddy top layers and therefore receives a slightly lower score.

Eventually the most feasible foundation type and construction method should be engineered based on the exact site-specific conditions, including soil conditions, water depth and ice conditions.

Table 4.20 Scores foundations options (criterium weight = 2%)

Wind farm site	**Estonia 1**	**Estonia 2**	**Latvia 1**	**Latvia 2**
Score	7	5	4	7

4.7 Ports: Logistics support and Operation & Maintenance

4.7.1 Introduction and methodology

Construction phase

The construction of an offshore wind farm requires a well- equipped infrastructure. Ports play a key role in the local supply chain, logistics support and other supporting infrastructure (such as the storage of components). Moreover, many large wind turbine components are manufactured at ports (monopiles, gravity-based foundations, assembly of floating wind turbines, etc.), particularly at ports with sufficient space for production halls, storage, assembly, and other loading areas. Another important requirement for a port to be suited for offshore wind is how well connected to its hinterland it is. There must be an efficient transport infrastructure (road, rail, or water).

It is usual for offshore wind components not to be directly shipped from the manufacturing facility to the offshore site. Often, components are delivered to an installation port where the components are pre-assembled and stored, before being loaded onto the vessel and transferred to the offshore wind farm site. Completing as much as possible of the installation and fabrication onshore saves time and money during the installation phase and makes a large part of the installation independent of offshore wind and wave conditions.

The maximum vessel size that a port can harbour is an important factor in the assessment of port feasibility. There is a wide variety of offshore vessels operating worldwide, and each of them has its own dimensions. As discussed in previous chapters, offshore wind turbines are growing. Offshore vessels must follow suit to allow them to install increasingly large turbines and other offshore parts. In the feasibility assessment, we consider the following dimensions as a baseline.

Table 4.21 Offshore installation vessel dimensions (reference: new offshore wind vessel, van Oord)[23]

	Length	Breadth	Draught
Van Oord vessel	175 meters	45	9

Another factor that could influence the feasibility of a port for the construction of a wind farm is the distance to the offshore site. Large distances are not generally a problem per se (a ship can simply sail for longer). For the Dutch wind farms Borssele 1-2, for example, jack-up vessels sailed from the Danish port in Esbjerg to the wind farm location over 24 times. Each time they retrieved 4 sets of turbine components, travelling 550 kilometres one-way. The Polish port of Gdansk is at a similar distance to the four wind farm sites. Future vessels will be able to carry more than 4 turbine sets, which means that even greater distances should not pose a problem.

As the offshore wind market is maturing rapidly, several new methods of installation are being tested. One example is the use of a floating platform with most of the turbine parts and other supply. This, compared to having to repeat the same sailing route many times, saves time and money.

It must be noted that the assessment of the ports in this study is based on the current situation. It is of course possible to modify ports (build new quays, increase maximum draught, etc.).

[23] https://www.vanoord.com/en/updates/van-oord-orders-mega-ship/

Operation and maintenance

The operation and maintenance centres for the execution of service and maintenance works of offshore wind farms are also usually run from ports, since there is ready access to mooring locations. The O&M base of a turbine manufacturer typically consists of an office, dressing and meeting rooms, workshop, a storage facility, and a quay for mooring and unmooring of Crew Transfer Vessels (CTVs), Service Operation Vessels (SOV), sometimes also helicopters or a combination of the previous option. A typical facility for an offshore wind farm of 80 – 120 wind turbines employs about 50 people, ranging from the technical engineers to the administrative and planning teams.

It must be noted that with the advent of supervisory control and data acquisition (SCADA) systems, the operation aspect of O&M can be done from anywhere in the world. Large operators often have centralized or regional control centres.

Preventive maintenance on a calendar basis is usually performed during the months with acceptable weather conditions and includes:

- offshore checks of various systems (hydraulics, mechanical, electrical, control, etc.)
- activities such as changing filters, tightening bolts, and lubricating mechanical parts.

Condition-based preventive maintenance are maintenance activities based on certain performance and wear levels obtained from data from (sub)systems and components. Unscheduled corrective maintenance can cover a wide range of problems, from resetting of (sub)systems to replacing (major) (sub)systems. The latter type of maintenance is usually more intensive in the early production years of a wind farm and at the end of the production life of a wind turbine. Most wind turbines need a major overhaul after 10 years, as not all main components last during the lifetime of the turbine. Major repairs are usually solved by specialized maintenance technicians who are not stationed in the local country.

Ice conditions

Planned offshore wind maintenance is usually done in the summer period when weather and water conditions are better suited for daily crossing. As discussed previously, all wind farm sites discussed in this study are ice-free in the summer. While maintaining the wind farm sites in the Baltic Sea might require more planning than a wind farm in a sea with no ice at all, it should not pose a major hurdle for the feasibility of wind farms.

Even though the industry standard currently encompasses simulation models, extensive turbine monitoring and preventive or even predictive maintenance, there is still need for unplanned, corrective maintenance, consisting of repairing breakdowns or other unscheduled emergency maintenance. These cases are increasingly rare, though. Moreover, offshore wind turbines have landing pads where technicians can be hoisted from a helicopter and so (some) maintenance in icy conditions is still possible.

The effect of icing conditions on the construction of wind farms is discussed in the paragraph ice conditions (paragraph 4.1).

Effect on local jobs

While the total number of jobs that is needed for maintaining a wind farm is relatively small, many turbine suppliers opt to work with local people as much as possible. Major repairs or overhauls are usually done by a specialized, international team of technicians.

Assessment framework and scores

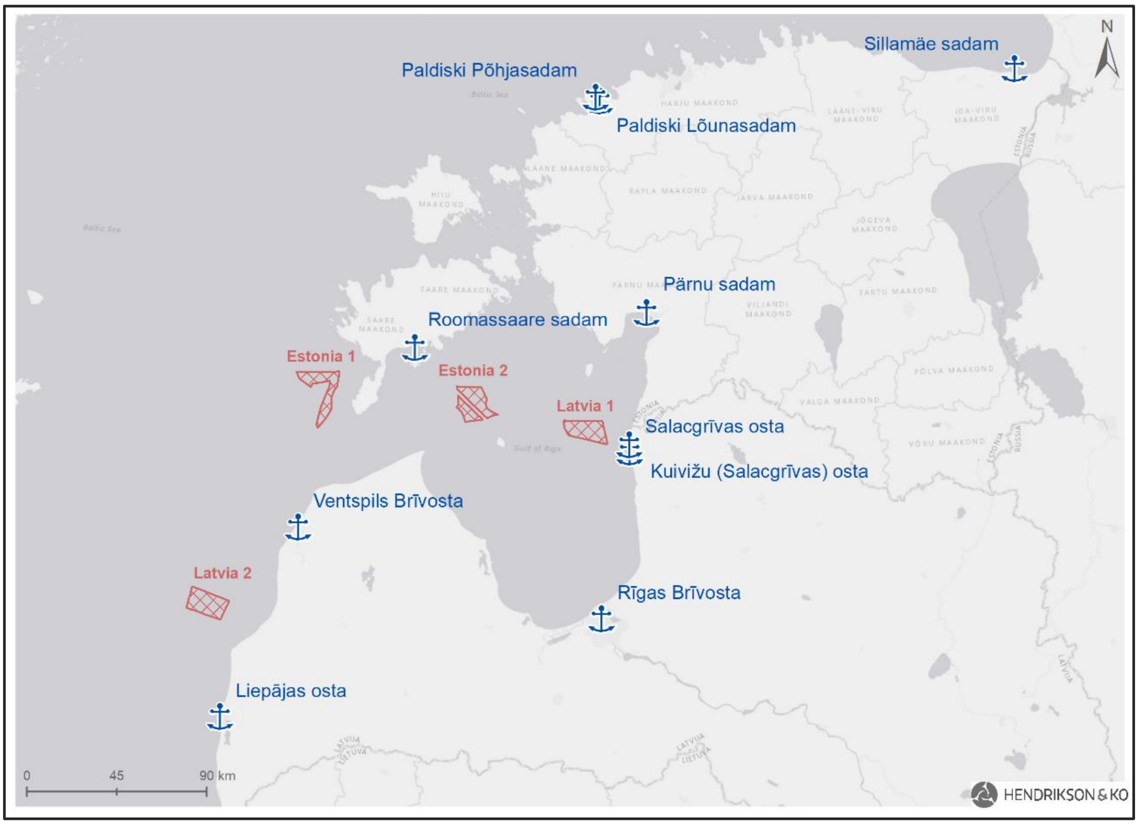
Each wind farm site receives a score based on their relative proximity to a port that has the base requirements for supporting the logistics in constructing an offshore wind farm. This encompasses primarily the maximum ship size and the location of the port within the national logistic network. Another factor in determining the score for this criterium is the proximity to a suitable O&M port base.

4.7.2 Data overview and description

Spatial data concerning ports surrounding the wind farm sites originates from the national Maritime Spatial Plans and were provided by the Estonian Ministry of Finance and the Ministry of Environmental Protection and Regional Development Republic of Latvia. Information about port capacities was collected from the official websites of Estonian and Latvian Ports.

The table below shows several ports to be considered in this assessment. They were chosen from the Estonian and Latvian MSP data, provided by the Estonian Ministry of Finance and the Latvian Ministry of Environmental Protection.

Figure 4.22 Wind farm sites and closest feasible ports



For operation and maintenance, smaller ports can be considered, too. Figure 4.23 shows the smaller ports in the dataset.

Figure 4.23 Smaller and larger ports

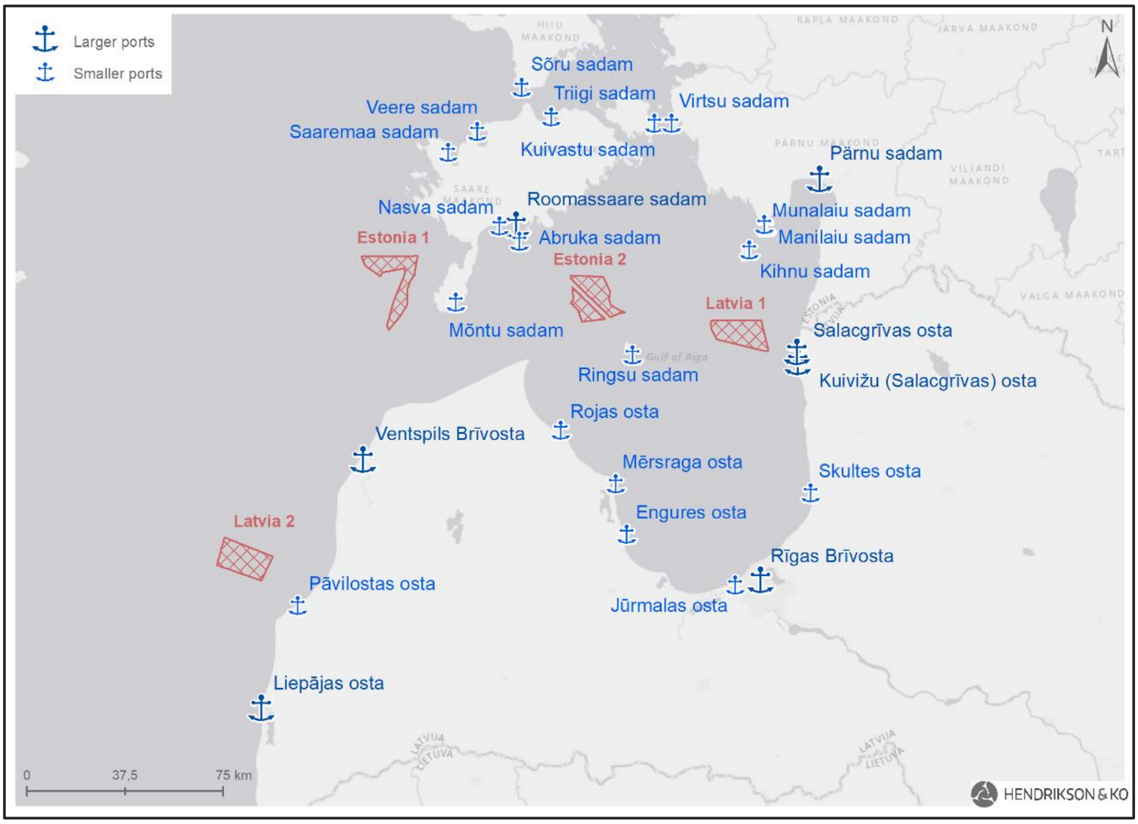


Table 4.22 Distances to ports and port properties

Port	Approximate distance to wind farm site (kilometres)				Max vessel length (m)	Max vessel breadth (m)	Max vessel draught (m)	Access to other transport modes
Estonia	**E1**	**E2**	**L1**	**L2**				
Paldiski North	263	385	410	360	250	45	14.5	Train, road
Paldiski South	263	385	410	369	250	26	12	Train, road
Pärnu	210	110	64	270	140	25	6.8	Road
Sillamäe	500	580	565	630	275	56	15.2	Train, road
Kuressaare	85	37	95	170	120	20	4.6	Road
Latvia	**E1**	**E2**	**L1**	**L2**				
Liepaja	200	250	300	71	240	35	11	Train, road
Ventspils	65	105	167	90	240-275	-	14.1 - 15	Train, road
Riga	200	130	100	265	300-320	-	15	Train, road
Salacgriva	180	92	50	280	70-157	-	2.2 - 5.6	Road

4.7.3 Assessment of wind farm sites

Construction

Several of the ports that are considered in the assessment do not fit the reference ship sizes as discussed in paragraph 4.7.1. These are the ports of Paldiski South, Pärnu and Kuressaare (due to max length, breadth, and draught) in Estonia, and the ports of Liepaja and Salacgriva (breadth, length, and draught) in Latvia. These ports are not considered when making the following assessment. For the ports of Ventspils and Riga in Latvia, data on the max vessel breadth is not available.

Even though there are differences between the different wind energy sites regarding the distance to the (closest) ports, the impact of distance to ports on feasibility is relatively small. Ports that are further away will increase the total cost of a project, but this difference will not make a location infeasible. The scores for each wind farm site will be slightly reduced for longer distances to the closest feasible port.

O&M

Each of the larger ports listed above could in principle harbour an O&M centre. The requirements for an O&M base are mostly based on the proximity to a wind site location i.e., the required vessels' size is almost never a decisive factor. This means that several other, smaller ports (see Figure 4.23) in the area could be suitable for an O&M base too.

Mitigating measures

The ports that are used as the basis for offshore wind farms do not necessarily have to be in the Estonian or Latvian territories. In fact, there are other ports at feasible distances, that are already used for offshore wind, that could be used as alternatives. The port at Gdansk (Poland), for example, is already used for offshore wind and is farther away, but still feasible (from 300km (Latvia 1) to 600km (Latvia 2)).

Moreover, some ports in this study were currently not seen as feasible, due to constraints to ship sizes. It must be noted that the assessment of the ports in this study is based on the current situation. It is of course possible to modify ports (build new quays, increase maximum draught, etc.).

4.7.4 Conclusion

While there are differences between the distances to the nearest feasible ports, these differences are not critical to the final scores.

Table 4.23 Final port scores (criterium weight = 2%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	8	8	8	8

4.8 Defence restrictions, surveillance & communication, and air traffic disturbance

4.8.1 Introduction and methodology

Defence restrictions

Various offshore areas may be used by the Ministries of Defence of either Estonia or Latvia. Possible defence activities that offshore wind farms may interfere with are (low-level) flying areas, firing ranges or unsafe zones, defence radar, practice areas for clearing mines and areas for testing military systems. The development of an offshore wind farm could lead to nuisance for these activities, which will lead to a lower score in the assessment. In case there are any other possible risk zones, for example a location where ammunition is dumped, there will be a lower assessment score too.

Surveillance and communication

Telecommunication and surveillance devices on the shore may rely on free line of sight. The construction of wind turbines may influence the effectiveness of these systems and other systems that rely on their functioning. The transport of radio and TV signals runs via various channels, such as telecom cables, fibre optic cables and sometimes through the air.

Wind farms may cause interference in the provision of maritime radio communications, and project developers are usually tasked with preventing and compensating interference with radio systems, for example by installing radio transponders. These solutions add research and material costs to the development of a wind farm.

If the construction of a wind farm site has negative effects on either of these factors, it will be given a lower score.

Air traffic disturbance

Airspaces are used for various forms of air traffic. These forms can consist of civil aviation, local flight movements of helicopters that fly back and forth between the coast and e.g., mining installations (oil and gas platforms), or border/coast guards during Search and Rescue operations. Depending on the airspace, different height restrictions may apply.

The wind farm areas that are discussed in this study were defined in the Estonian and Latvian Maritime Spatial Plans (MSP). In these plans, air traffic routes and possible impacts of wind farms on those routes were already considered. The generally positive assessment in this paragraph is therefore not a coincidence, as these effects were already considered when the four wind farm sites were defined.

Assessment frameworks and scores

Each wind farm site receives a score based on their effects on defence areas, surveillance/communication devices and air traffic. The effect size is based on the prevailing height constrictions or similar spatial complexities.

4.8.2 Data overview and description

Input concerning defence restrictions, surveillance and communication and air traffic disturbances for the wind farms sites were given by the Estonian and Latvian governments (Ministries of Defence, Ministry of Environmental Protection, Regional Development Republic of Latvia). The Latvian Maritime Spatial Plan's info about areas of national defence interest was used as supporting data (see Figure 4.24 below).

Latvia

The Latvian Coast Guard Service controls the maritime regime. In performing this task, it uses the 8 Global Maritime Distress and Safety System (GMDSS) base stations that are managed by the State Defence and Military Objects Procurement Centre and are located along the entire coast of Latvia (see Figure 4.24).

The Latvian wind farm development sites are partially affected by the state military and surveillance interests. Wind farm site Latvia 1 is in an area where there aren't any direct restrictions, but near to the Eastern border of Latvia 1 is a shipwreck. In other hand wind farm site Latvia 2 is in a surveillance tower buffer zone which applies certain restrictions to the wind farm development. Like wind farm site Latvia 1, there are shipwrecks located in the East and South-East corners of the development site.

Figure 4.24 Latvian military interest areas

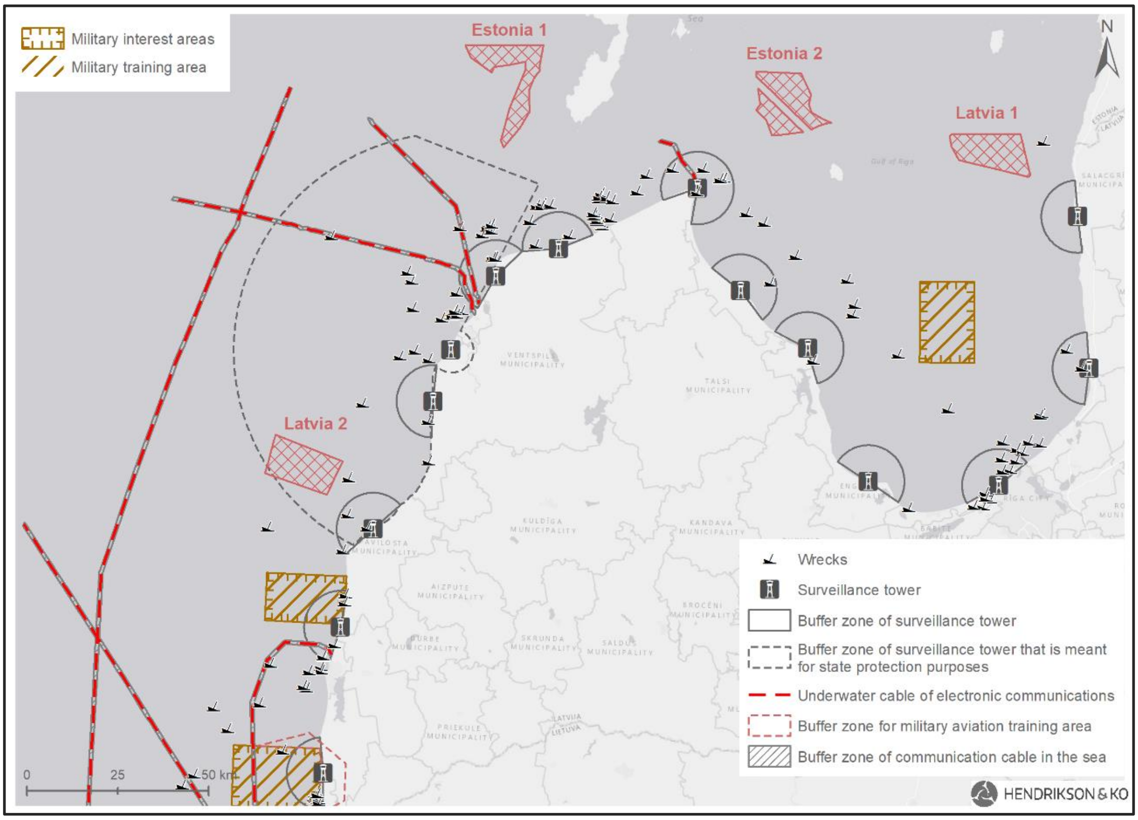
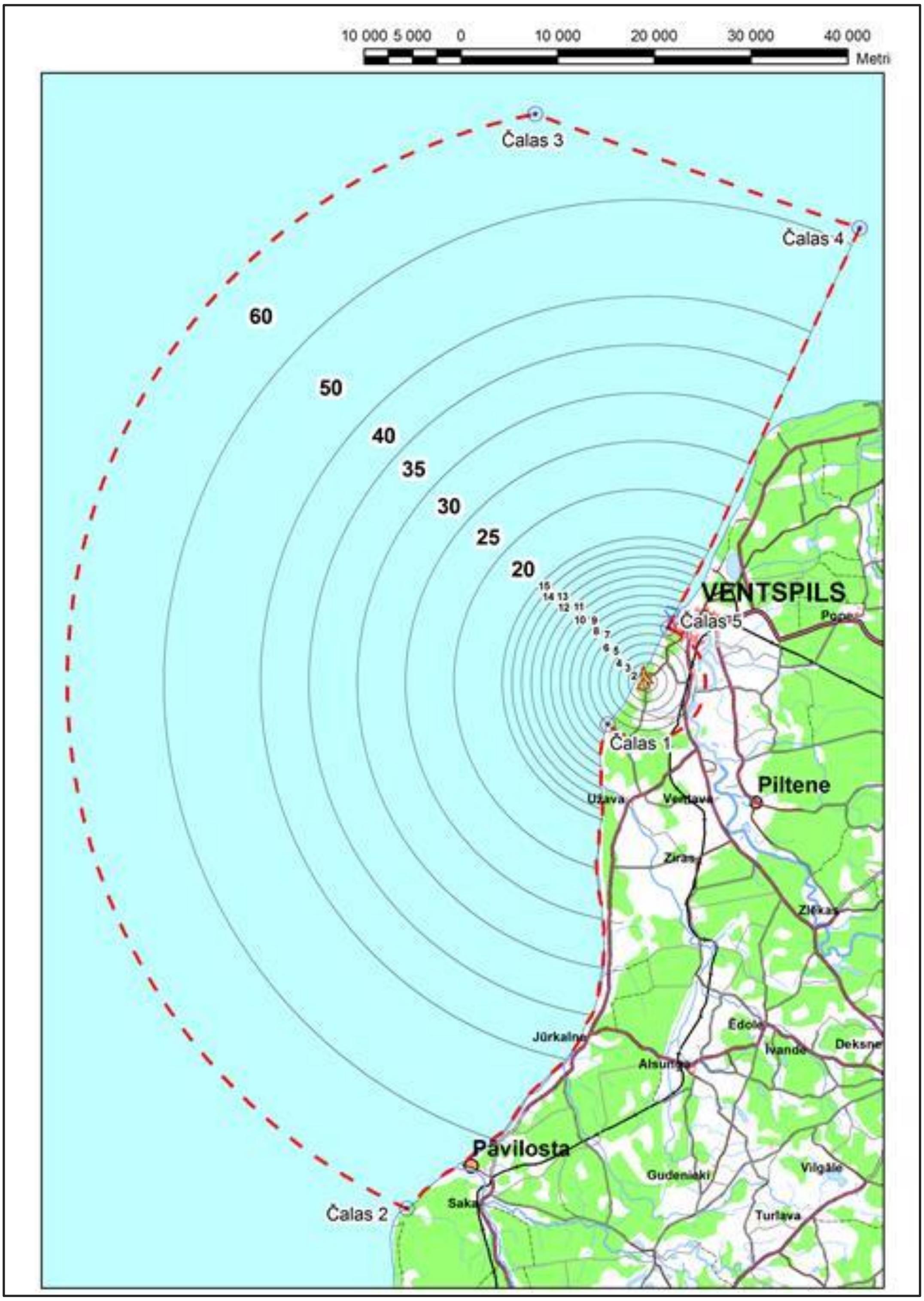


Figure 4.25 Height restrictions for navigational radar[24]



[24] Source: Ministru kabineta 2014. gada 20. maija noteikumi Nr. 246 "Noteikumi par to valsts aizsardzības vajadzībām paredzēto navigācijas tehnisko līdzekļu un militāro jūras novērošanas tehnisko līdzekļu sarakstu, ap kuriem nosakāmas aizsargjoslas, aizsargjoslu platumu un tajās nosakāmajiem būvniecības ierobežojumiem". https://likumi.lv/ta/id/266334

There are currently no plans to further expand and develop new radar systems that could affect either of the wind energy sites. The Latvia 2 zone is directly within a surveillance buffer zone. Moreover, a group of 14 shipwrecks in the south-eastern part of this wind energy site will pose additional complexities when constructing a wind farm. Further research is needed to assess this issue completely.

While building higher than the permitted height (max 198 - 251 meters) within the restriction zones is not technically impossible, it would add additional technical and spatial-planning complexity resulting in significant extra costs to the development of the wind farm. Construction could be permitted, but if effects on radar zones must be mitigated – either by building a new radar station or changing the current one – these costs are added to the development cost.

Estonia

Unfortunately, there is no similar geographical data for the Estonian side. Their written response is summarized in the table below.

Estonian military interest areas do not overlap with either of the wind farm sites Estonia 1 and Estonia 2.

Table 4.24 Defence restriction data table

Wind area site	Height restriction (in meters)	Other restrictions
Estonia 1	422 – 693 meters	
Estonia 2	131 - 195 meters	
Latvia 1	198 – 400 meters	
Latvia 2	198 – 251 meters	Group of shipwrecks

4.8.3 Assessment of wind farm sites

There are no wind farm sites situated within any of the Latvian military and surveillance interest areas, such as surveillance buffers, underwater cables, aviation training areas or military interest areas. The only exception is Latvia 2, which is within the buffer zone of a surveillance radar.

Wind farm site Estonia 1

There is a height restriction on the Estonia 1 wind farm of 422 to 693 meters. Given that the tip height of the reference turbine used in this report is only 300 meters, this restriction has no impact on the feasibility of Estonia 1. The southern part of the site is within the defined restriction zones for a Latvian radar, based on Figure 4.25. However, after consulting the specific Latvian regulations [25], there appear to be no restrictions when building farther than 60 kilometres from the radar site.

[25] Ministru kabineta 2014. gada 20. maija noteikumi Nr. 246 "Noteikumi par to valsts aizsardzības vajadzībām paredzēto navigācijas tehnisko līdzekļu un militāro jūras novērošanas tehnisko līdzekļu sarakstu, ap kuriem nosakāmas aizsargjoslas, aizsargjoslu platumu un tajās nosakāmajiem būvniecības ierobežojumiem". https://likumi.lv/ta/id/266334

Wind farm site Estonia 2

The Estonia 2 site is within a restricted zone as defined by the Estonian Ministry of Defence. As the maximum building height is only between 131 and 195 meters, this severely limits the types of wind turbines that can be built.

Wind farm site Latvia 1

The Latvia 1 site is within a restricted zone as defined by the Estonian Ministry of Defence. As the maximum building height is between 198 and 400 meters, additional research needs to be done to assess what the exact height restrictions are and what possibilities remain for the construction of wind turbines. The lower limit of 198 meters would impose significant restrictions for offshore wind, however a maximum of 400 meters is enough for the reference turbine used in this study.

Wind farm site Latvia 2

The Latvia 2 wind farm site is within the range of a Latvian navigational radar. As the maximum height there is 198 – 251 meters, this severely limits the types of wind turbines that can be built. Moreover, a group of shipwrecks lies directly within the zone. The restrictions present are comparable to Estonia 2.

4.8.4 Mitigating measures

The effects on defence areas or radar installations can usually be mitigated by constructing a new radar and/or researching the actual effect of the wind farm on radar reception. The latter might lead to a change of regulations. However, this is a time-consuming matter. For the wind farm sites Estonia 1, Latvia 1, and Latvia 2, mitigating measures may be necessary.

Effects on radar can also be reduced by optimizing wind farm layouts or using smaller wind turbines.

4.8.5 Conclusion

Estonia 1 is the only wind farm site not directly affected by height restrictions. For the other wind farm sites, the significance of the height restrictions is reflected in their final scores. This means that Latvia 1 has a higher score than both Estonia 2 and Latvia 2. The height restrictions for Estonia 2 give it the lowest scores out of all four wind farm sites.

Table 4.25 Final scores defence, communication, air traffic (weight percentage = 5%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	9	3	6	4

4.9 Shipping routes

4.9.1 Introduction and methodology

A wind farm in the Baltic Sea might influence shipping safety because ships can collide with wind turbines and because the presence of a wind farm leads to an increased risk of collision between ships. It is also conceivable that failure of a wind turbine could cause effects on ships. Effects on shipping safety are therefore an important consideration in decision-making. A collision at sea can lead to major environmental and personal consequences. Examples of this (although not due to wind turbine collisions) are the oil spills that occurred in 2002 in shipping disasters off the north coast of Spain (the single-hull oil tanker Prestige) and the southeast coast of England (the Tricolor).

Apart from the chance of accidents, the presence and perhaps more importantly, the construction of a wind farm may hinder the regular traffic on the Baltic Sea. Required detours or reduced traffic capacity of a shipping lane have a negative impact on the Baltic Sea traffic and may have financial or planning effects.

Grid connection

Crossings and proximities with shipping routes impacts not only the feasibility of the wind farm itself. The grid route must also be considered. For grid connection cables that cross or lie parallel with a shipping lane, generally extra precautions must be taken to prevent accidental collisions with anchors or fishing nets. Generally, this is done by increasing the burial depth of the cable at these sites, increasing laying costs. Moreover, any reduced traffic capacity effects must also be considered, as the laying of the cable (especially parallel to a shipping lane) will most likely impact the possible ship traffic there.

Assessment framework and scores

For this chapter we will evaluate how many shipping routes must be crossed or what the proximities of each wind farm to these shipping routes are. Shipping intensity will be an extra factor in the final score.

4.9.2 Data overview and description

The data for shipping routes and traffic intensity for both Estonia and Latvia originate from the Maritime Spatial Plan source data packages. Estonian and Latvian shipping routes and water traffic intensity sets were provided by the Estonian Ministry of Finance. Data for shipping routes and traffic intensity on the Estonian and Latvian sides is extensive and comparable at the same level.

Figure 4.26 Fairways and water traffic areas

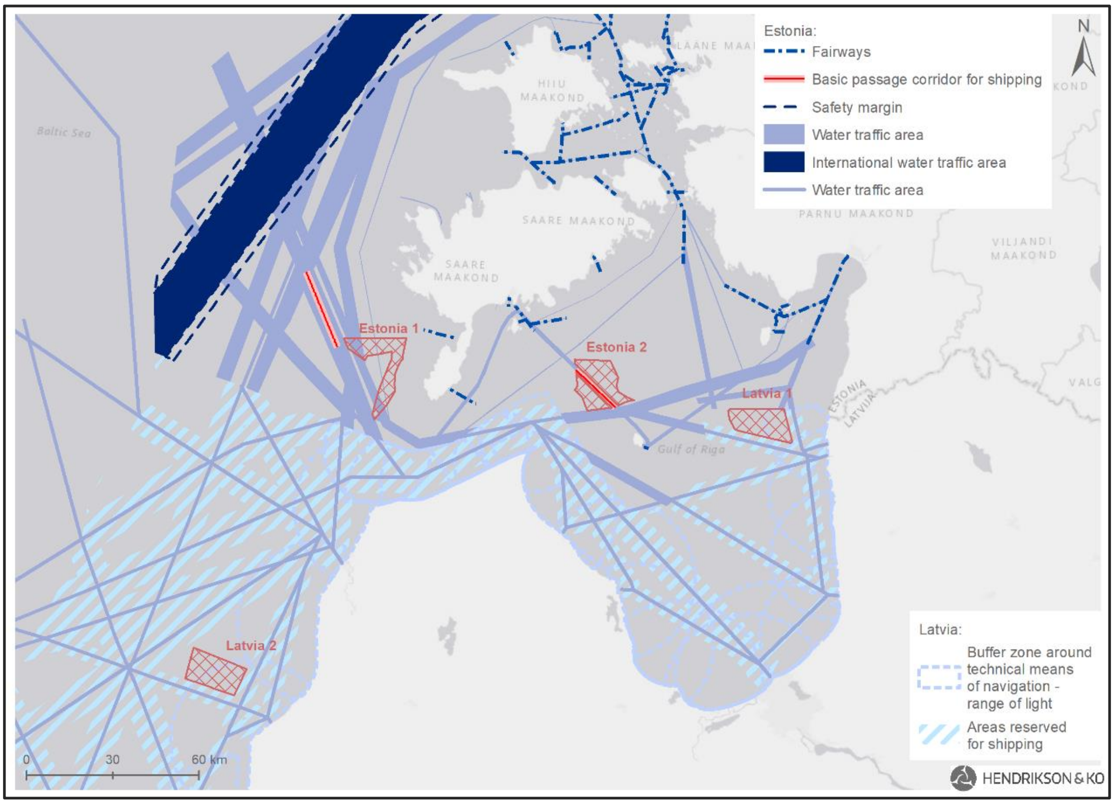
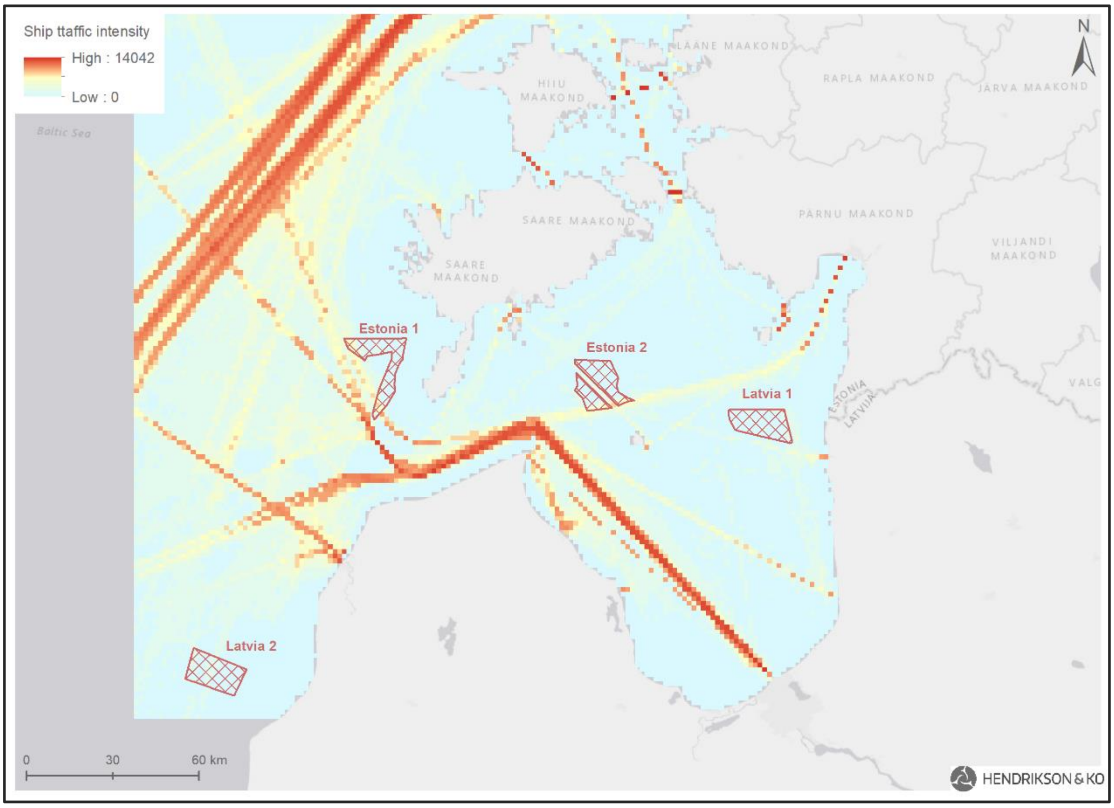


Figure 4.27 Shipping intensity



4.9.3 Assessment of wind farm sites

Wind farm site Estonia 1

The wind farm site Estonia 1 is intersected by a shipping route / water traffic in its South and North-West corners. In the south area, several different shipping lanes cross at a short distance. Moreover, the wind farm site is quite close to the area reserved for shipping on the Latvian border. The nearby (at some points less than a kilometre) shipping routes have relatively high traffic. There are however several alternative shipping routes nearby.

Wind farm site Estonia 2

Estonia 2 consists of two parts, opposite of a shipping route. This means that it is completely intersected by the main shipping lane from Kuressaare to Ruhnu. However, the intensity of the traffic is low compared to the other wind farm sites.

Wind farm site Latvia 1

The Latvia 1 is just outside the main shipping areas on the Latvian border near Salacgriva. Moreover, the shipping intensity data suggests that there is relatively low traffic here.

Wind farm site Latvia 2

Wind farm site Latvia 2 is situated more to the south than the other wind farm sites and therefore has less of an impact on the traffic that goes into the Gulf of Riga. There is very little shipping traffic nearby.

4.9.4 Mitigating measures

To reduce the effects on shipping safety, several measures are conceivable. Determining possible measures and "establishing" their effectiveness should be part of further studies into cumulative effects of not just a single wind farm site, but the whole Baltic Sea traffic and future developments combined.

Vessel traffic management

A Vessel Traffic Service (VTS) is a marine traffic monitoring system to track, monitor and manage vessel traffic in critical areas such as harbours, coastal areas, and wind farms. With increasing maritime traffic at sea or on inland waterways, the use of a Vessel traffic management system may reduce risks. Increased safety and security requirements at borders and critical infrastructure installations such as offshore wind farms also raise the need for high performance surveillance.

Additional marking and identification of wind turbines

Good lighting, marking and identification of wind turbines has a preventive effect on collisions with wind turbines especially for working boats, fishing boats and recreational boats in the situation with transit. This can be included as a precondition in permits or tenders, for example.

Grid connection

A risk based burial depth (RBBD) analysis can be performed to gain insight into the probability of damage to the cable caused by shipping activities in the area during its lifetime. This should be followed up by a "risk based burial depth" study in a later phase.

4.9.5 Conclusion

There are differences between the wind farm areas regarding their effect on shipping traffic. Estonia 1 is situated in a more high-density traffic zone and might have a relatively high impact compared to the other wind farm sites. Neither of the wind farm sites has an extremely negative effect on shipping routes. However, Estonia 1 and Estonia 2 are both intersected by shipping routes. Traffic intensity on these routes is highest for Estonia 1.

Table 4.26 Shipping routes final scores (percentage weight = 1%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	7	8	9	9

4.10 Additional capacities / impact on other parks

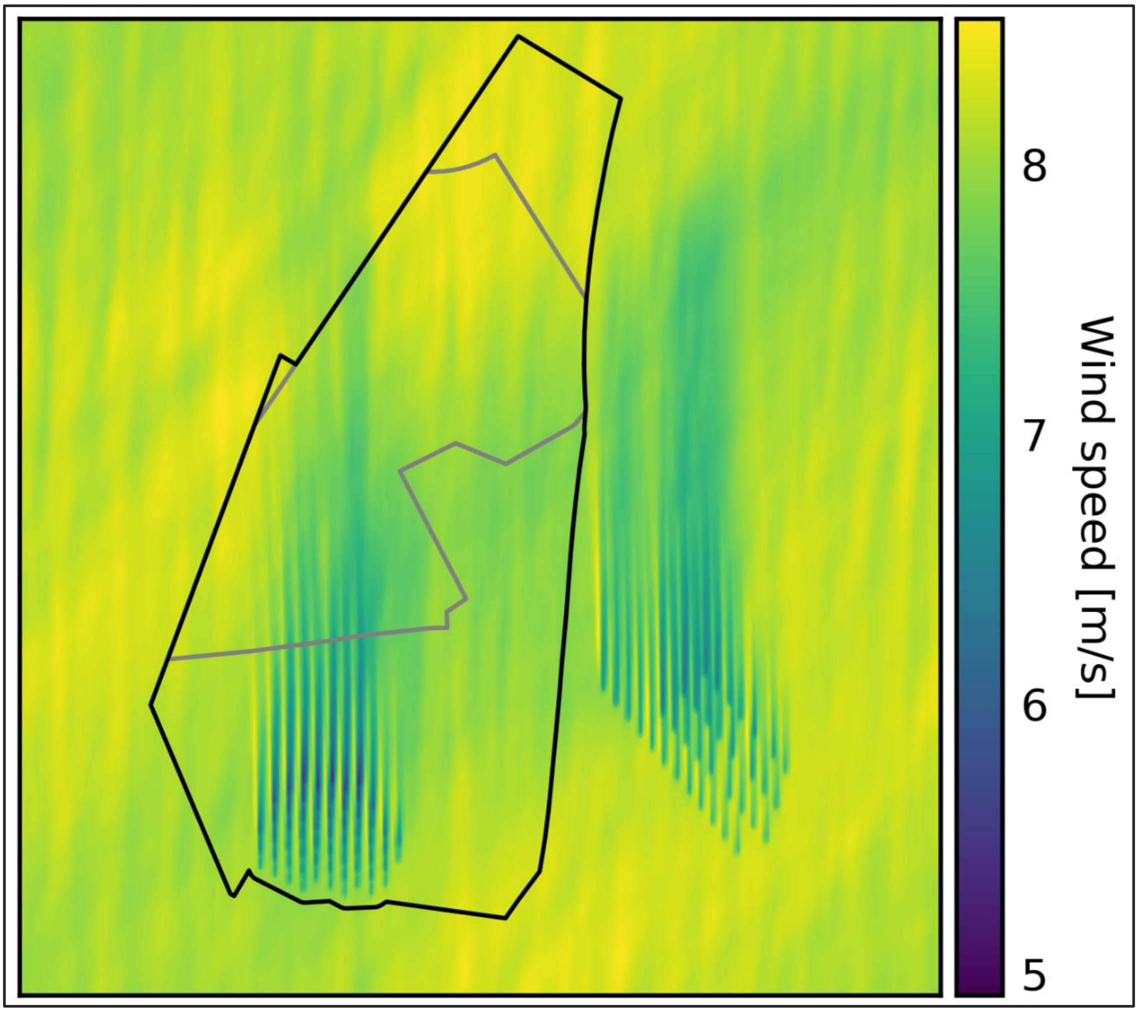
4.10.1 Introduction and methodology

Wake effects

The distance between turbines and the orientation of the wind farm are determining factors for the so-called wake effect. This is the effect in which the wind field of a turbine is disrupted by the presence of other turbines. Wake effects reduce the yield of a wind farm. This effect become smaller as the distance between wind turbines increases. The expected energy yield also depends on the operational reliability of the wind turbines and depends on weather conditions and the season.

In the case of other nearby wind farms, this effect can be greatly increased. A wind farm area may leave a 'wind shadow' that stretches for several kilometres (see Figure 4.28 and Figure 4.29), affecting other wind farms. These effects must be considered for each new wind farm that is constructed.

Figure 4.28 Modelled wake effects at the Hollandse Kust (noord) wind farm (the Netherlands)



Source: Whiffle

Figure 4.29 Wake effects impact condensation

Shared resources

While wind farms may influence other farms nearby negatively, building wind farms (relatively) close together can also give advantages. The most important advantage is the possibility of sharing resources, such as the O&M facilities, and a grid connection. Sharing O&M resources can greatly reduce costs but requires wind farm operators and owners to work together. Sharing a grid connection can be an extremely significant cost reduction, as the grid connection is a major part of the total cost of a wind farm.

Both options require extensive planning ahead and should be considered in each stage of a wind farm project.

Cumulative effects and other criteria

Several other criteria in this report are based on the effects that a singular wind farm area has on its surroundings, and how that impacts the feasibility. It must be noted that cumulative effects, where the combined effects of several wind farm sites in the Baltic Sea are different than the effect of just a single site, are not considered in this report. Examples of cumulative effects are the impacts from multiple wind farms in the Baltic Sea on bird and bat migration or underwater noise. In the continuing development of wind farm sites in the Gulf of Riga and/or the Baltic Sea, these cumulative effects should be an integral part of the assessment for each development step.

Assessment framework and scores

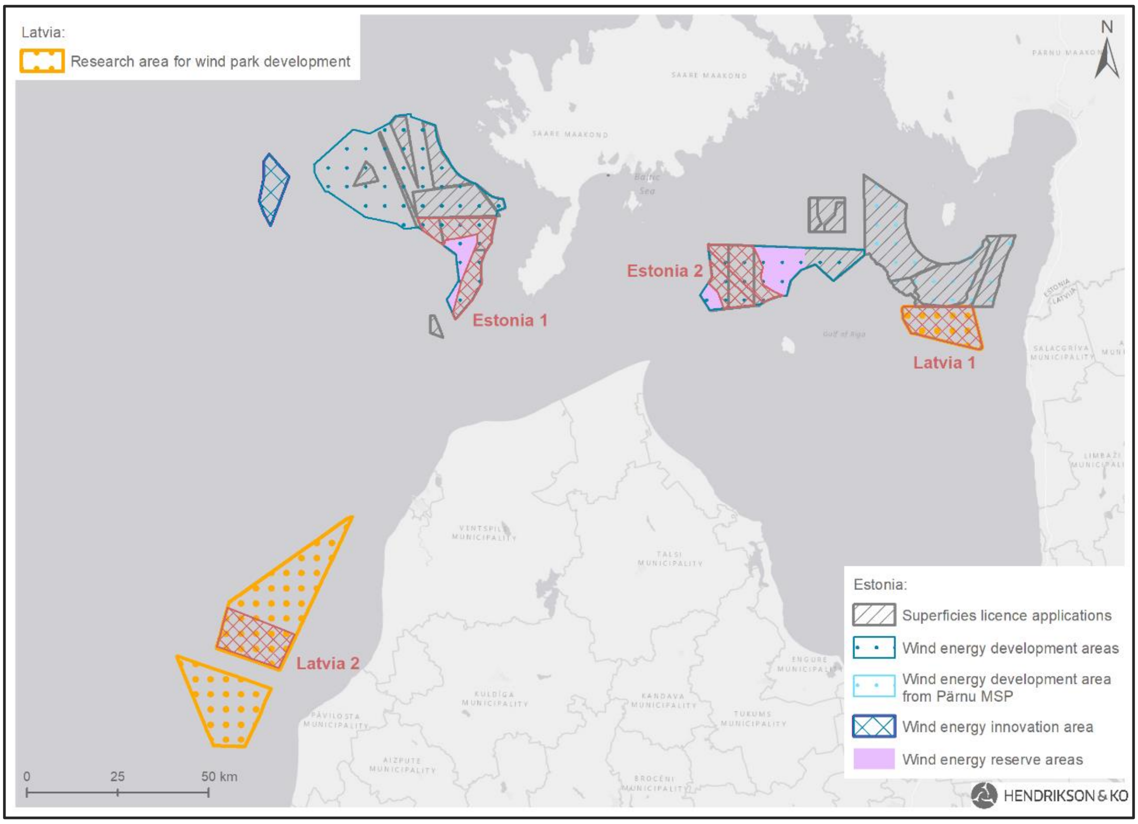
Each wind farm receives a score based on the effects on other planned wind farms or wind farm areas. While positive synergy is possible – a grid connection can be shared – these effects can also be negative in the case of wake effects and the cumulative negative effects of other wind farms. The final score will be a balance of these assessment factors.

4.10.2 Data overview and description

Wind energy development, innovation and reserve areas and areas with superficies licence applications data for both Estonia and Latvia originate from the Maritime Spatial Plan source data packages. Estonian and Latvian wind energy development sets were provided by the Estonian Ministry of Finance as input for the new Estonian Maritime Spatial Plan.

For the Estonian side, there is data about overall wind development areas, wind energy development areas from regional MSP-s, wind energy innovation and reserve areas. The Estonian side is also covered with superficies licence applications data. On the Latvian side, there is data that refers only to research areas for wind park development

Figure 4.30 Wind energy areas



4.10.3 Assessment of wind farm sites

Wind farm site Estonia 1

The Estonia 1 wind farm site is part of a bigger offshore wind energy development area, as defined in the Estonian MSP. Moreover, several licence applications are already under consideration for this larger wind energy area. The size of the area allows for a large amount of extra wind farms – on top from the currently assessed area. A shared grid connection in this area is something that should be considered in the future.

In terms of wake effects, the current layout of the larger area (generally North-West to South-East) is perpendicular to the prevailing wind direction (generally south-west). Perpendicular layouts are, in general, a positive factor to wake effects.

Wind farm site Estonia 2

Estonia 2 is part of a larger wind energy area as defined in the MSP. Moreover, several licence applications are already under consideration for this larger wind energy area. The size of the area allows for a large amount of extra wind farms – on top from the currently assessed area. A shared grid connection in this area is something that should be considered in the future.

In terms of wake effects, the current layout of the larger area (generally West to East) is close to the prevailing wind direction (generally West, South-West). Wake effects on other wind farms might be more of an issue compared to Estonia 1.

Wind farm site Latvia 1

The Latvia 1 wind farm site lies on the border of the exclusive economic zone with Estonia. This means that it is very likely that international effects must be considered when constructing the wind farm. The sharing of a grid connection with future wind farms in the North – the wind energy development area from Pärnu – is possible but might be more complicated than a solitary connection, as it would be an international project.

In terms of wake effects, the current layout of the larger area (generally West to East) is close to the prevailing wind direction (generally West, South-West). Wake effects on other wind farms might be more of an issue compared to Estonia 1. Moreover, as the wind energy development area from Pärnu lies in the prevailing wind direction, wake effects on possible wind farms there must be considered.

Wind farm site Latvia 2

Latvia 2 is part of a larger research area for wind park development. In the north, Latvia 2 is connected to this area. To the south, a shipping route separates it from the larger development area. A shared grid connection in this area is something that should be considered in the future. The shipping route however must be considered. As Latvia 2 is much farther away from the border with Estonia, international effects are not likely to be a consideration.

In terms of wake effects, the current layout of the larger area (generally North-West to South-East) is perpendicular to the prevailing wind direction (generally West, South-West). This is generally a positive layout regarding potential wake effects.

4.10.4 Mitigating measures

To reduce a negative impact on other wind farms, the layout of each wind farm site may be precisely calculated and aligned with each other. To assess the feasibility and possibility of a shared grid connection, development of all wind energy areas could be done in an overarching cooperation. The ELWIND project is a first step in that direction.

4.10.5 Conclusion

The Estonia 1, Estonia 2 and Latvia 1 wind sites have both has advantages and disadvantages regarding the possibilities of other nearby wind farms. Latvia 2 receives a slightly higher score, as for the wind farm layout, the proximity to other wind farm areas and wake effect criteria negative effects do not stand out.

Table 4.27 Final additional capacities / other park score (criterium weight = 2%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	7	7	7	8

4.11 Fisheries and impact on fish

4.11.1 Introduction and methodology

Wind farms and grid connections could have an impact on the fishery sector and could impact fish and fish habitats.

Wind farm

Fishery sector

Usually, normal fishing methods (i.e., with trawling ships) are forbidden inside wind farms because of potential damages on the wind turbines, cables, or construction ships. This could have an impact on the fishing sector because of the reduced space for fishing in the Baltic Sea and Gulf of Riga. Especially wind farm developments in places with a high fishing intensity have an impact on fisheries.

Fish and fish habitats

Construction activities of a wind farm and the grid connection can impact fish, benthos, and fish habitats due to the underwater noise, vibrations, shipping movements and soil disturbance. Underwater noise due to pile driving of the monopiles or due to seismic research related to soil surveys can disturb or cause hearing loss of fish and other underwater life (like seals and other sea mammals). This is not the case for foundation options that do not use pile driving, like gravity-based structures or suction buckets.

During the operational phase there are benefits for fish and fish habitats in wind farm sites. For example:

- Protection from fisheries due to calm waters
- increased ecological opportunities for fish and coral reefs due to foundations and scour protection
- increased business opportunities for aquaculture: Aquaculture, like fish shellfish and seaweed farms, is expected to have positive combined effect with the presence of offshore wind farms. Inside a wind farm the intensity of shipping, fishing or other usages is probably lower compared to the open sea. The calm waters within a wind farm and especially around the foundations and scour protection of wind turbines make for a suitable growth environment for aquaculture

Grid connection

The impact of the grid connection on the fishing sector during the operational phase is limited because the grid is usually buried under the seabed. Possible hazards from the fishing sector on grid connection are intense trawling and anchoring above the grid connection cable.

The grid connection could have an impact on fish, benthos, and other underwater life due to the soil disturbance during the construction phase and possible electromagnetic fields during the operational phase.

Assessment framework and scores

Each wind farm site will be provided a score based on the fishing intensity and presence of fish and fish habitats. Wind farm sites located in an area with a high presence of fish and important fish habitats will be given a low score. Wind farm sites options located in an area with a low presence of fish and important fish habitats will be given a low score.

4.11.2 Data overview and description

Data for fishing intensity for both Estonia and Latvia originate from the Maritime Spatial Plan source data packages. Estonian and Latvian datasets were provided by the Estonian Ministry of Finance and Ministry of Environmental Protection and Regional Development Republic of Latvia. Additional supporting data for fish spawning areas were collected from HELCOM 2021 report on the Essential fish habitats in the Baltic Sea (see Figure 4.32).

Estonian datasets cover coastal fishing and trawling intensity which overlaps with the Latvian territorial seas. Latvian MSP provided overall fishing intensity and an additional dataset for fish habitats (see Figure 4.31).

Figure 4.31 Fishing intensity and trawling intensity

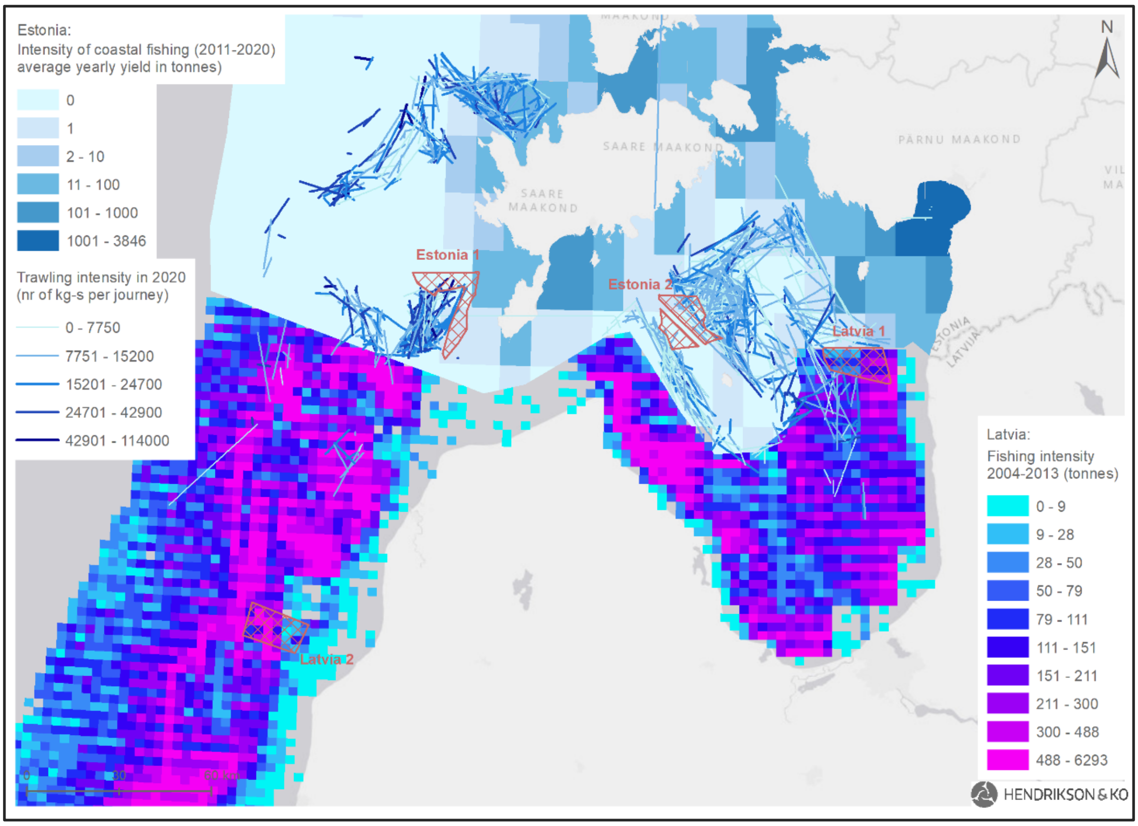
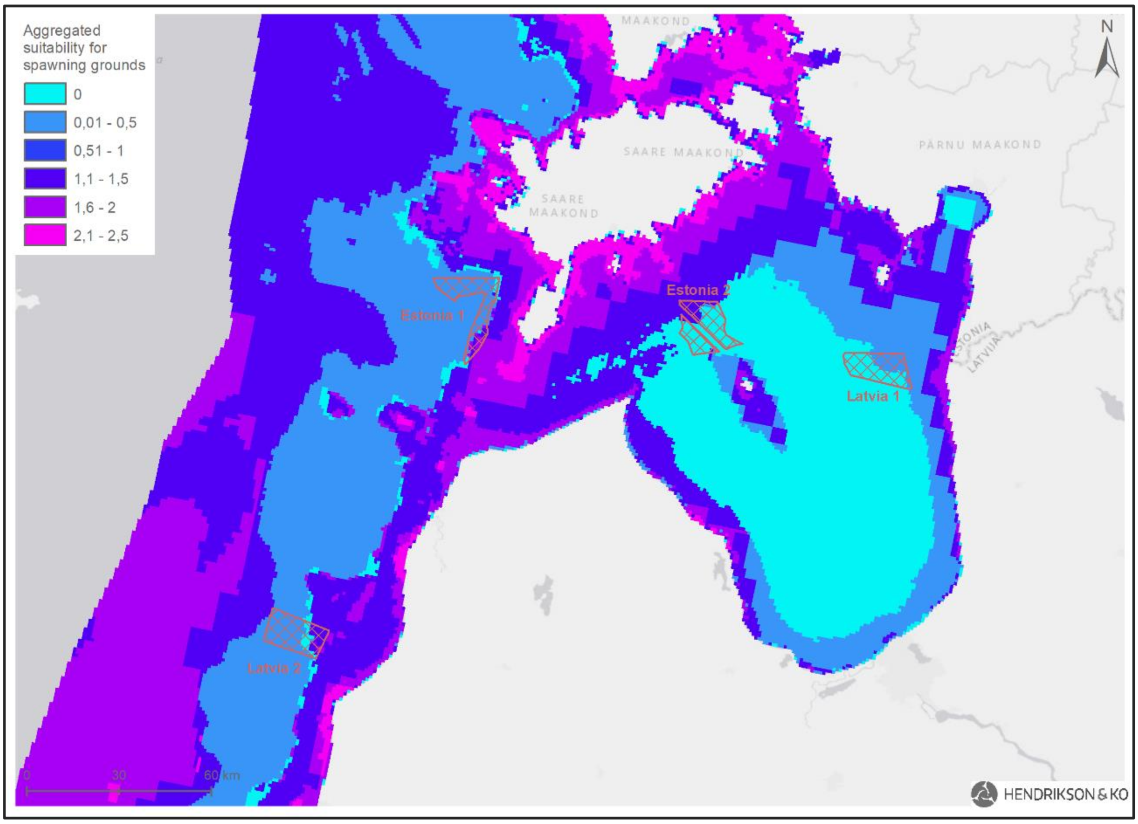


Figure 4.32 Aggregated suitability for spawning grounds



In general, fishing is carried out with varying intensity depending on the region and period in the Baltic Sea and Gulf of Riga. Fishing is prohibited only in a few limited areas, and this is to protect the fish. The aggregated suitability for spawning grounds is highest near the shallow and coastal areas.

4.11.3 Assessment of wind farm sites

Wind farm site Estonia 1

Wind farm site Estonia 1 is positioned in an area with a low intensity of coastal fishing, low trawling intensity. However, data is missing about the intensity of general open water fishing. Finally, wind farm site Estonia 1 has a low suitability for spawning grounds.

Wind farm site Estonia 2

Wind farm site Estonia 2 is positioned in an area with a low intensity of coastal fishing, low trawling intensity. However, data is missing about the intensity of general open water fishing. Moreover, wind farm site Estonia 2 has a low suitability for spawning grounds. Estonia 1 and Estonia 2 have a similar low effect on the fishing sector and fish habitats.

Wind farm site Latvia 1

Wind farm site Latvia 1 is positioned in an area with a low trawling intensity. In terms of total fishing intensity between 2004 and 2013 (see Figure 4.31), it is comparable to Latvia 2. The difference in fish species is that Latvia 1 has very low flounder, sprat, or cod catches, but high herring catches.

Finally, wind farm site Latvia 1 has a low suitability for spawning grounds.

Wind farm site Latvia 2

In terms of total fishing intensity between 2004 and 2013 (see Figure 4.31) Latvia 2 is comparable to Latvia 1. The difference in fish species is that Latvia 1 has very low flounder, herring, or cod catches, but high sprat catches.

Finally, wind farm site Latvia 2 has a low suitability for spawning grounds.

4.11.4 Mitigating measures

Fishing sector

A possible mitigating measure is to allow the fishing sector to co-use the wind farm site and allow certain fishing methods. In the Netherlands, normal fishing with trawling ships is forbidden inside modern wind farms because of potential damages on the wind turbines, cables, or construction ships. However, passive fisheries (with lines and baskets) are allowed inside wind farms.

Finally, fishing is prohibited only in a few limited areas in the Baltic Sea and Gulf of Riga. Therefore, there are still many fallback options for the fishing sector to go to nearby places suitable for the fisheries.

Underwater noise

A major impact of constructing the foundations of wind turbines with monopiles on fish and other underwater life is underwater noise. Extra measures could be implemented to reduce this impact, such as using a lower pile energy, an acoustic deterrent device or noise reducing bubble screens. Or using foundation options that does not include pile driving (see paragraph 4.6).

4.11.5 Conclusion

All four wind farm sites have a low intensity of fishing and fish habitats. Moreover, mitigation measures are available to reduce the impact on the fishery sector and the impact on fish and fish habitats. Final conclusions are however hard to make because of lacking or incomparable data: no data on trawling intensity in Latvia and no Estonian data about the intensity of general open water fishing (only coastal fishing data). To conclude, high scores are given for all four wind farm sites, but no maximum scores.

Table 4.28 Scores fisheries and impact on fish (criterium weight = 2%)

Wind farm site	**Estonia 1**	**Estonia 2**	**Latvia 1**	**Latvia 2**
Score	8	8	8	8

4.12 Migration routes and feeding area of birds

4.12.1 Introduction and methodology

Offshore wind turbines can have effects on sea birds and migrating land birds. The most important effects during the operational phase are:

- Collisions of birds with turbines: Birds can collide with the rotor blade or the mast and can be impacted by the turbulence behind the wind turbines. This could cause bird victims or injuries. The danger is higher during the night.
- Disturbance and habitat loss for birds in the impacted areas. Birds avoid an area around the wind farm because of the wind turbines. This results in habitat loss for birds.
- Barrier effects on flight paths and migration routes: birds need to change their flight or migration routes.

During the construction phase, birds could be disturbed by pile driving activities[26] and shipping movements. In particular, the lights of ships and constructions can attract birds. Consequently, birds can collide with the ships and constructions or get disorientated. However, these effects are expected to be less significant compared to the effects during the operational phase.

In this assessment, the bird migration routes, and possible feeding and resting areas are identified. Predicting the number of birds at risk of colliding with wind turbines is a core component of an Environmental Impact Assessment (EIA). This is not in the scope of this study and should be performed for a concrete offshore wind farm project.

Assessment framework and scores

Each wind farm site will be provided a score based on the occurrence of birds and the presence of nearby bird migration routes and bird habitats. Wind farm sites located in an area with a high occurrence of birds and/or high presence of nearby bird migration routes and bird habitats will be given a low score. Wind farm sites located in an area with a low occurrence of birds and/or low presence of nearby bird migration routes and bird habitats will be given a high score.

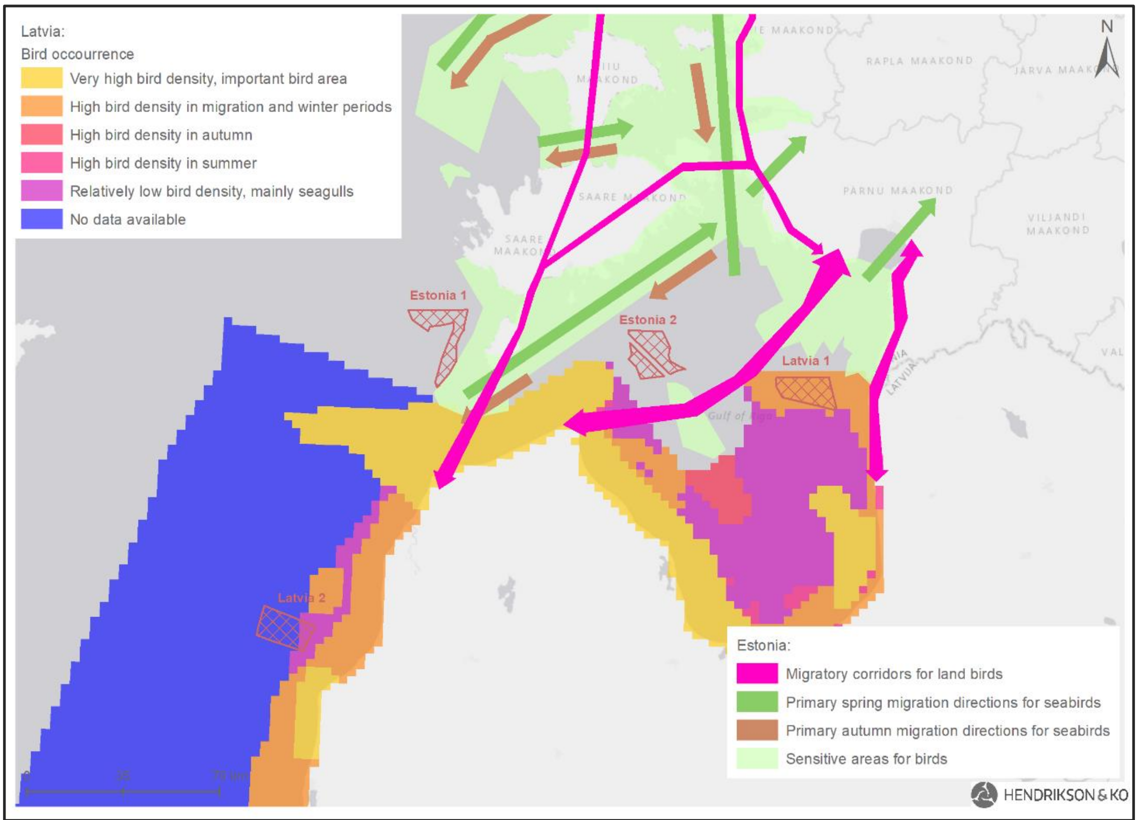
4.12.2 Data overview and description

The bird migration routes and feeding area data originates from the study commissioned by the Ministry of Finance as an input for Estonian Maritime Spatial Plan. Estonian Ornithological Society carried out a studies called “Eesti merealal paiknevate lindude rändekoridoride kohta andmete koondamine ja vastavate kaardikihtide loomine ning analüüsi koostamine tuuleparkide mõjust lindude toitumisaladele.” and “Lindude peatumisalade analüüs“. The dataset for the Latvian bird occurrence comes from the ministry of Environmental Protection and Regional Development Republic of Latvia.

The datasets for Estonia and Latvia are quite different by nature. On the Estonian side there are bird migratory corridors for sea and land birds and bird sensitive areas. These migration corridors overlap with the Latvian part of the Gulf of Riga. The Latvian territorial sea is covered with bird occurrence data in different seasons. Concerning the Latvia 2, only a small amount of that area is covered with bird occurrence data.

[26] This is not the case for foundation option without pile driving, like gravity-based structures or suction buckets.

Figure 4.33 Bird migratory routes, sensitive area for birds and bird occurrence



4.12.3 Assessment of wind farm sites

Wind farm sites Estonia 1 en 2 are positioned outside of sensitive areas for birds. Moreover, it is impossible to compare the bird occurrence between Latvia 1 en Latvia 2, because for the largest area of Latvia 2 the data is missing (Figure 4.33).

No known bird migration route from the Estonian MSP crosses one of the wind farm sites. However, there are bird migration routes close to wind farm site Estonia 1, Estonia 2, and Latvia 1. With the proximity of migration routes nearby, the likelihood of bird collision victims is higher for the wind farm sites. There is no data available for this study about possible bird migration routes near wind farm site Latvia 2. However, if the bird migration routes of the Estonian MSP are extrapolated, this will either overlap or go alongside Latvia 2. The Latvian MSP states that the EEZ[27] waters of Latvia are located on the bird migratory path of the Baltic Sea. The area is used directly by 30 species of aquatic birds and marine birds. Figure 4.33 shows that the highest bird occurrence is directly alongside the western coastline of Latvia. Therefore, we can assume that Latvia 2 is positioned outside, but nearby the main bird migration route.

[27] Exclusive Economic Zone

4.12.4 Mitigating measures

Mitigation measures are available to reduce the impact on birds during the construction and operational phase.

Construction phase

Possible mitigating measures during the construction phase are:

- Execute construction activities outside op periods with the presence of many species sensitive to disturbances near the wind farm stie.
- To reduce the impact of lightning of construction ships on birds, minimal and bird-friendly lightning could be used.
- To reduce the impact of underwater noise due to pile driving, noise reducing measures could be implemented.

Operational phase

Possible mitigating measures during the operational phase are:

- Larger, and therefore fewer wind turbines, causes a reduction of bird victims.
- Using temporary shutdowns at moments with a high bird occurrence. This should be combined with a detection system (radar, visual observation, or cameras) or prediction system. For example: by using a prediction model, wind turbines can be stopped before peak bird migration takes place.
- To reduce the impact of obligatory navigation lightning on wind turbines, minimal and bird-friendly lightning could be used.

4.12.5 Conclusion

All wind farm sites are given the same score for the criteria migration routes and feeding areas birds. Although no known bird migration route crosses one of the wind farm sites, all wind farm sites have a high likelihood of migrating birds nearby. Mitigating measures can reduce the impact of the wind turbines on the migrating birds. Moreover, no wind farm sites are located in a sensitive area for birds or an area with a very high density of birds. Therefore, 7 points are given for each wind farm site.

Table 4.29 Scores bird migration routes and feeding areas (criterium weight = 4%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	7	7	7	7

4.13 Migration routes of bats

4.13.1 Introduction and methodology

The most important negative effect of the offshore wind farms on bats are related to victims of collision with wind turbine blades or local differences in pressure caused by the rotation of the wind turbine blades. In contrast with birds, bats are often attracted by wind turbines. Therefore, there are no effects from wind turbines on habitat loss or barrier effects. Moreover, the open sea is not a typical habitat of bats to breed, rest or forage. The presence of bats in the wind farms sites is mainly due to migration activities. Like birds, bats also perform long-distance migration between their breeding and wintering sites. In Northern Europe, migratory bat species are often detected along the coastline of the Baltic Sea particularly during migration seasons in the spring and autumn.

European migratory bats, e.g., Nathusius pipistrelle (Pipistrellus nathusii), the noctule (Nyctalus noctula) and the particolored bat (Vespertilio murinus), are known to migrate long distances from their breeding sites in the high latitudes to hibernate in the central and western parts of the continent. Bat migration typically converges along topographic barriers, including coastlines large rivers and mountain ranges. In Northern Europe, the migratory routes for bats could follow the coastlines of the Baltic Sea and continue to the German North Sea.[28]

In this assessment, available data on bat migration routes are identified. Predicting the number of bats at risk of colliding with wind turbines is a core component of an Environmental Impact Assessment (EIA). This is not in the scope of this study and should be performed for a concrete offshore wind farm project.

Assessment framework and scores

Each wind farm site will be provided a score based on the presence of nearby bat migration routes. Wind farm sites located in a migration route of near a migration route will be given a low score. Wind farm sites without a bat migration route nearby will be given a high score.

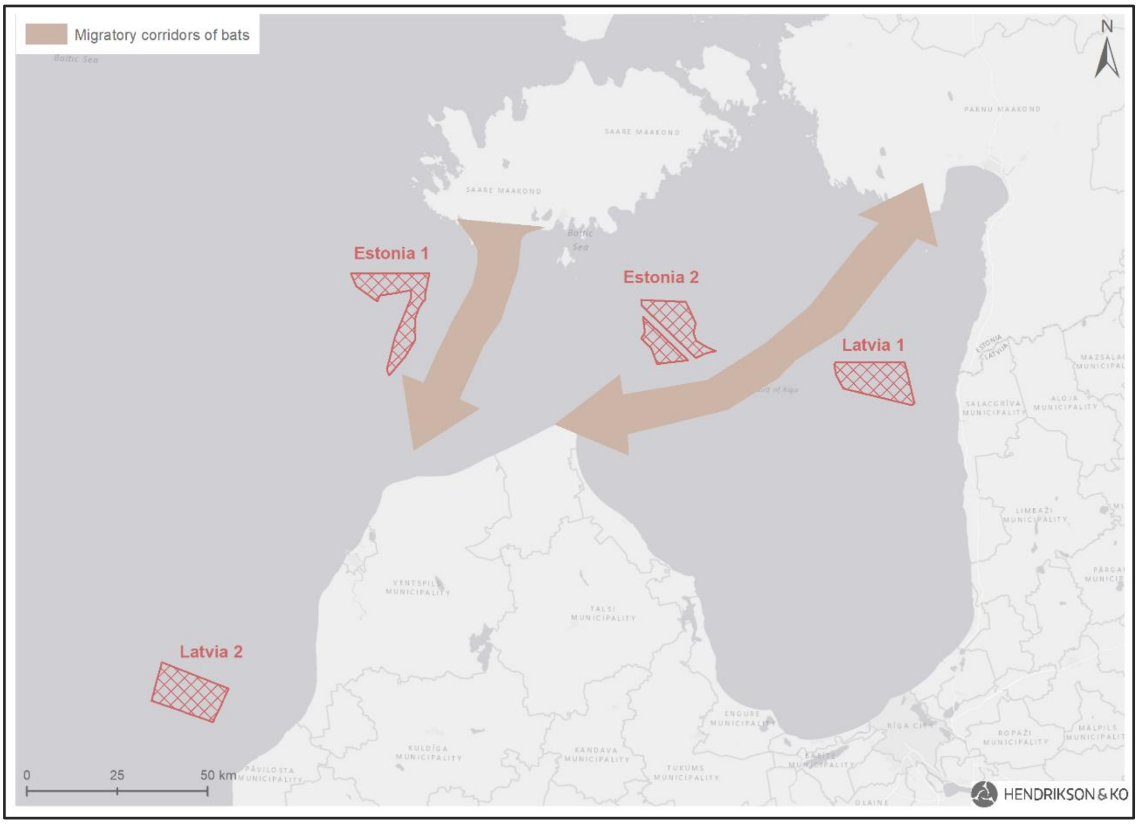
4.13.2 Data overview and description

The bat migration routes overlapping Estonian and Latvian territory originates from the study commissioned by the Ministry of Finance as an input for Estonian Maritime Spatial Plan. Estonian Fund for Nature carried out a study called “Nahkhiirte uuring Veiserahul ja Kerjurahul 2016. aasta augustis, septembris ja oktoobris.” and” Saaremaalt lõuna või edela suunas üle mere toimuva nahkhiirte rände uuring.”.

Bat migratory information is only provided by the Estonian side. On the Latvian side bat, migratory info is lacking.

[28] Ijäs et al. (2017) Evidence of the Migratory Bat, Pipistrellus nathusii, Aggregating to the Coastlines in the Northern Baltic Sea.

Figure 4.34 Bat migration routes



Source: MSP Estonia[29]

4.13.3 Assessment of wind farm sites

No known bat migration route from the Estonian MSP crosses one of the wind farm sites. However, there are bat migration routes close to wind farm site Estonia 1, Estonia 2, and Latvia 1. With the proximity of migration routes nearby, the likelihood of bat collision victims is higher for the wind farm sites. There is no data available for this study about possible bat migration routes near wind farm site Latvia 2. However, if the bat migration routes of the Estonian MSP are extrapolated, this will either overlap or go alongside Latvia 2. Moreover, bat migration typically follows the coastlines of the Baltic Sea. To conclude, we can assume the same effects for all 4 wind farm sites.

4.13.4 Mitigating measures

The best method to reduce the number of bat victims is to reduce to number of rotations per minute of a wind turbine to less than 2 on moment on moments when a high bat activity is expected in the wind farm. Bats normally migrate in the autumn and spring season, during:

- high temperatures
- slow wind speeds
- specific wind directions (to be examined)
- between sunrise and sunset.

[29] https://www.msp-platform.eu/countries/estonia

Given these parameters it is possible to effectively reduce the number of bat victims without a significant loss of electricity production. Finally, larger wind turbines and therefore, less wind turbines, reduces the total amount of bat victims.

4.13.5 Conclusion

All wind farm sites are given the same score for the criteria migration routes bats. Although no known bat migration route crosses one of the wind farm sites, all wind farm sites have a high likelihood of bat migration routes nearby. Mitigating measures can reduce the impact of the wind turbines on the migration bats. Therefore, 7 points are given for each wind farm site.

Table 4.30 Scores bat migration routes (criterium weight = 4%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	7	7	7	7

4.14 Habitats of seals

4.14.1 Introduction and methodology

Wind farm site

Construction activities of a wind farm and the grid connection can impact seals (but also porpoise) due to the underwater noise, vibrations, shipping movements and soil disturbance. Underwater noise can disturb or create hearing loss of seals, because of pile driving of the monopiles[30] or seismic research related to soil surveys.

During the operational phase, the impact on seals is limited. The loss of habitat due to the physical space of the wind farm is neglectable related to the total habitat of seals.

Grid connection

The operational phase of the grid connection is not relevant for the fishing sector, because the grid is placed or buried on the seabed. The grid connection could have an impact on fish, benthos, and other underwater life due to the soil disturbance during the construction phase and possible electromagnetic fields during the operational phase.

Assessment framework and scores

Each wind farm site will be provided a score based on the presence of seals. Wind farm sites located in an area with a high presence of seals or seal habitats will be given a low score. Wind farm sites located in an area with a low presence of seals or seal habitats will be given a high score.

4.14.2 Data overview and description

The seal habitat datasets overlapping Estonian and Latvian territory originate from the study commissioned by the Ministry of Finance as an input for the Estonian Maritime Spatial Plan. In 2019 MTÜ Pro Mare provided the Estonian Ministry of Finance a report “Eesti mereala planeering: Hüljeste leviku ja merekasutuse hinnang. Rakendusliku uuringu lepingu NR 1.9-1/404-1 aruanne.” Additional supporting data from HELCOM 2018 report on the distribution of Baltic seals was also used to assess the impact on seal habitats.

There is extensive data available about the habitat of ringed seals in the Gulf of Riga. Estonian. For wind farm side there’s a general assessment available for the distribution of ringed and grey seals based on HELCOM report.

[30] This is not the case for foundation option without pile driving, like gravity-based structures or suction buckets.

Figure 4.35 Wintering and breeding grounds of ringed seal

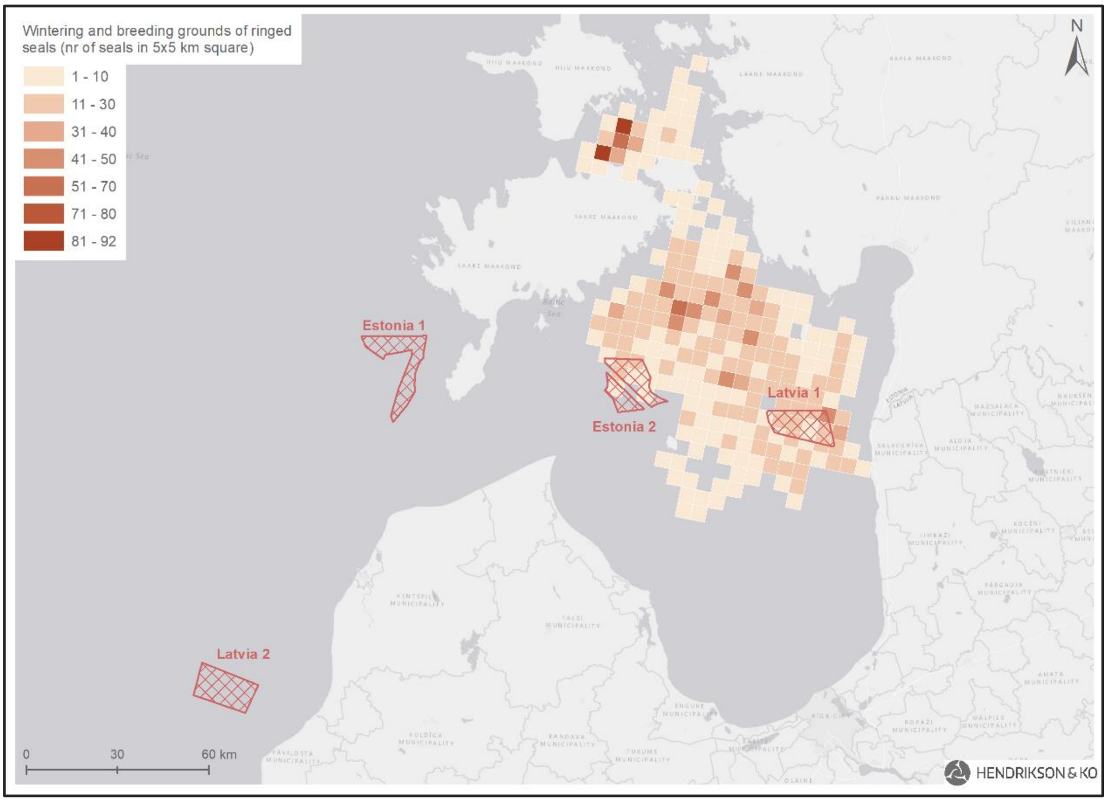


Figure 4.36 Migration areas of ringed seal

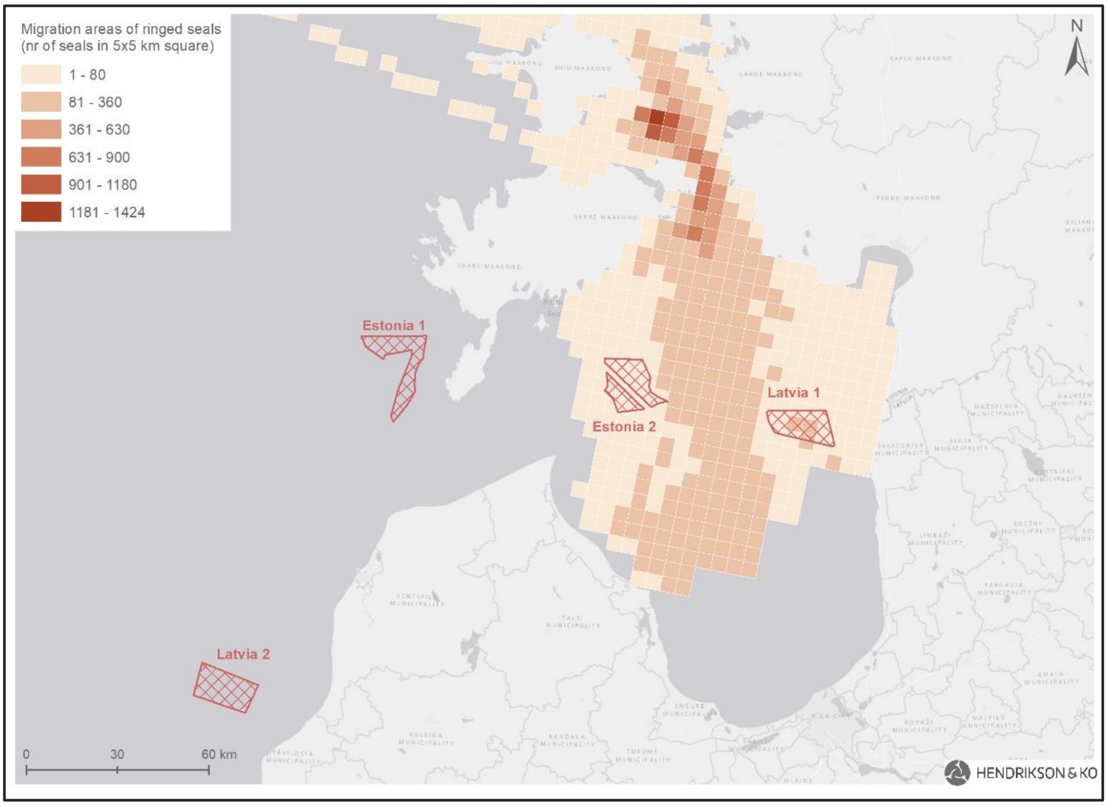
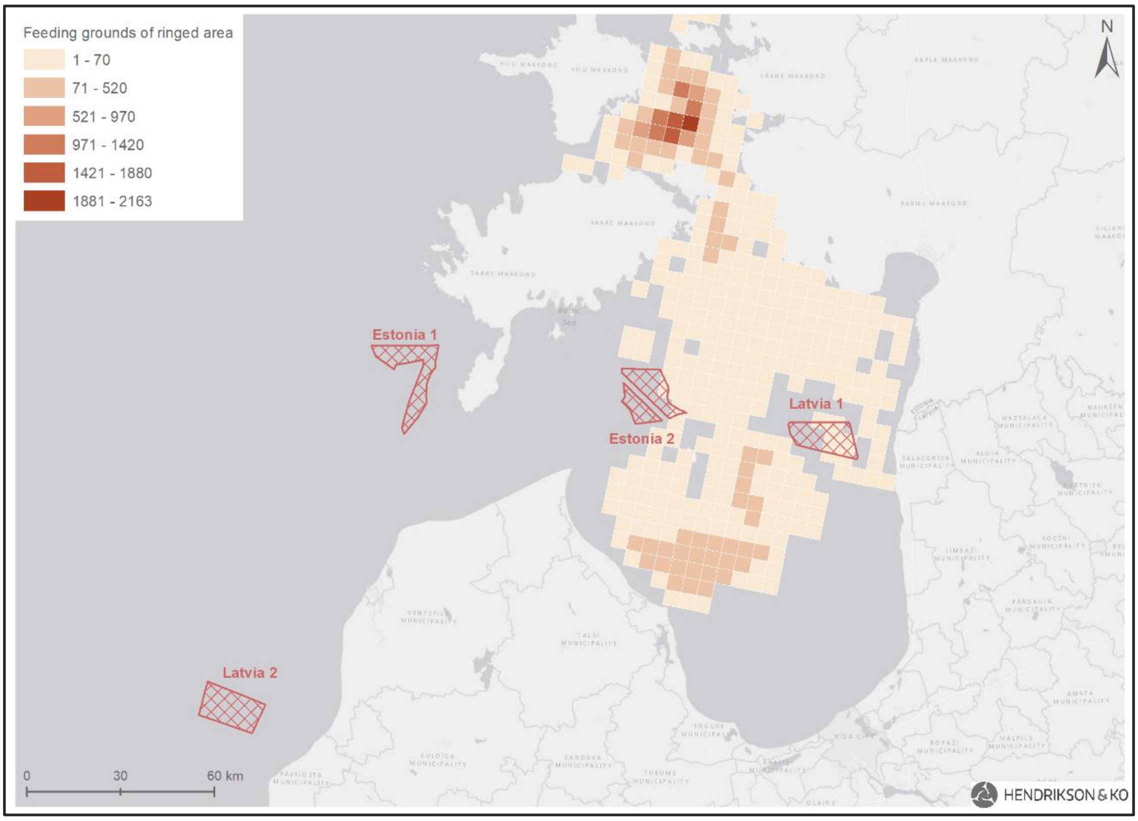


Figure 4.37 Feeding grounds of ringed seal



4.14.3 Assessment of wind farm sites

Four marine mammal species are resident in the Baltic Sea: the grey seal, harbour seal, ringed seal, and the harbour porpoise (HELCOM, 2018)[31]. Grey seals rest and forage across the whole Baltic Sea. The population of grey seals is similar for the whole Baltic Sea. Moreover, grey seals in the Baltic Sea have an upwards population trend in population last two decades. In contrast, harbour seals are not present in in the proximity of the Gulf of Riga. Harbour seals are mostly present in the southwest of the Baltic Sea[32]. Harbour Porpoise is not present in near the wind farm sites, but is mostly at Denmark's Eastern shore (HELCOM, 2018).

Ringed seals

Ringed seals however are well represented near the wind farm sites. The ringed seal is a locally distributed species in the Baltic Sea, whose sub-populations cover mostly the Gulf of Bothnia, but can also be found in the Archipelago Sea and the Gulf of Finland and the western marina areas of Estonia (Gulf of Riga and Väinameri).

Ringed seals swim under the ice and make breathing holes in it. The pups spend their winter in lairs under the snow hidden from predators and weather conditions. The breeding of ringed seal is restricted by the availability of suitable sea ice. The ringed seal needs compact and very close pack ice where snow can accumulate, which makes it particularly sensitive to climate change. This is probably one of

[31] http://stateofthebalticsea.helcom.fi/biodiversity-and-its-status/marine-mammals/

[32] Helcom core indicator report (2018). Distribution of Baltic seals. Key message.

the reasons why the Population of ringed seals are decreasing in the Gulf of Riga (HELCOM, 2018). The seals also use ice platforms for moulting and resting. Outside of the ice seasons, ringed seals often stay at coastal haul outs.

If we look at the data, wind farm site Estonia 2 and Latvia 1 overlap with the Ringed seal wintering, breeding, migration and feeding ground. These are also the regions with the largest ice conditions, compared to Estonia 1 and Latvia 2, which are more positioned in the open sea. Therefore, a lower presence of the ringed seal is expected near wind farm site Estonia 1 and Latvia 2, compared to Estonia 2 and Latvia 1.

4.14.4 Mitigating measures

A major impact of constructing the foundations of wind turbines with monopiles on seals and other underwater life is underwater noise. Extra measures could be implemented to reduce this impact, such as using a lower pile energy, an acoustic deterrent device or noise reducing bubble screens. Or using foundation options that does not include pile driving (see paragraph 4.6).

Finally, construction of the windfarm could be planned outside of periods with ice conditions to protect breeding ringed seals.

4.14.5 Conclusion

The presence of grey seals, and especially the ringed seal, can’t be excluded in all wind farm sites. It is expected that the presence of the ringed seal is higher in wind farm sites Estonia 2 and Latvia 1. Mitigating measures can reduce the impact of the wind turbines on the habitat of seals. Therefore, 8 points are given for Estonia 1 and Latvia 2, and 4 points are given to Estonia 2 and Latvia 1.

Table 4.31 Scores habit of seals (criterium weight = 4%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	8	4	4	8

4.15 Nature protection areas and Natura 2000

4.15.1 Introduction and methodology

Natura 2000 is a European network of core breeding and resting sites for rare and threatened species, and some rare natural habitat types which are protected. Any plan or project likely to have a significant negative effect on a Natura 2000, either individually or in combination with other plans or projects, shall undergo an Appropriate Assessment to determine its implications for the site. These negative effects could also emerge outside of Natura 2000 areas. For example, migrating or foraging birds, seals or bats can be impacted by a wind farm outside of a Natura 2000 area, while these animals are species for which the Natura 2000 area is designated.

In Estonia and Latvia there are also other appointed and proposed nature protection areas with certain nature values (see next paragraph).

Regarding the grid connection, it is also important to consider the surrounding nature protection areas when designing the cable route. The grid connection could have an impact on the nature values from the protected nature areas due to the soil disturbance during the construction phase and possible electromagnetic fields during the operational phase.

Assessment framework and scores

In general, a larger distance to Natura 2000 areas or other nature protection areas provides a lower chance to significant negative effects on Natura 2000 areas. Wind farm sites located inside or in the direct proximity of Natura 2000 areas or other nature protection will be given a low score. Wind farm sites located outside and not in the direct proximity of Natura 2000 areas or other nature protection will be given a high score.

4.15.2 Data overview and description

Nature protection and Natura 2000 datasets for both Estonia and Latvia originate from the Maritime Spatial Plan source data packages. Estonian datasets were provided by the Estonian Ministry of Finance and Latvian datasets by the Ministry of Environmental Protection and Regional Development Republic of Latvia. Both datasets give an extensive overview of nature protection areas in the Baltic Sea.

The following types of nature protection areas can be distinguished (see Figure 4.38):

- Estonia:
    - Proposal for offshore protected areas that are not yet protected, but they are suggested to be taken under protection by the Estonian MSP.
    - Proposed protected areas are partly onshore national park areas, where the proposed protection areas would be extended to offshore areas, as the offshore construction and other similar activities would have an impact on the national parks.
    - Natura 2000 Sites of Community importance hold nature, cultural and historical value to residents or tourists.
    - Natura 2000 Special Protection are Bird and Habitat Directive sites, which hold an important significance in bird and different species protection.
    - Nature reserves are national nature protection areas.

- Conservation area is an area designated for the protection of different habitats. In order to ensure its preservation, the impact of the proposed activities have to be assessed. All activities detrimental to the site are prohibited. Conservation area highly overlaps with the Natura 2000 areas.

- Latvia:
    - Marine protected area without functional zone (also Natura 2000) is an area where the protected area has not been divided into functional zones by the goals of protection and use.
    - Marine protected area neutral zone (also Natura 2000) is designed to ensure the sustainable development of the area, the functioning of the ports and the necessary infrastructure, as well as to ensure the economic activity of coastal populated areas and the development of tourism infrastructure.
    - Marine protected area nature reserve zone area (also Natura 2000) is an area where it is prohibited to:- perform activities that cause mechanical damage to a specially protected biotope – a rocky seabed – including the installation of a WPP and extraction of mineral resources;- install new disposal sites; perform industrial extraction of algae and mussels.
    - Investigation area of nature values are further research areas to determine the existing natural values.
    - Biosphere Reserve landscape protection zone is a nature reserve area that includes a multitude of diverse natural and semi-natural habitats. It encompasses vast areas of primeval and traditional landscapes.

Figure 4.38 Natura protection and NATURA 2000 areas

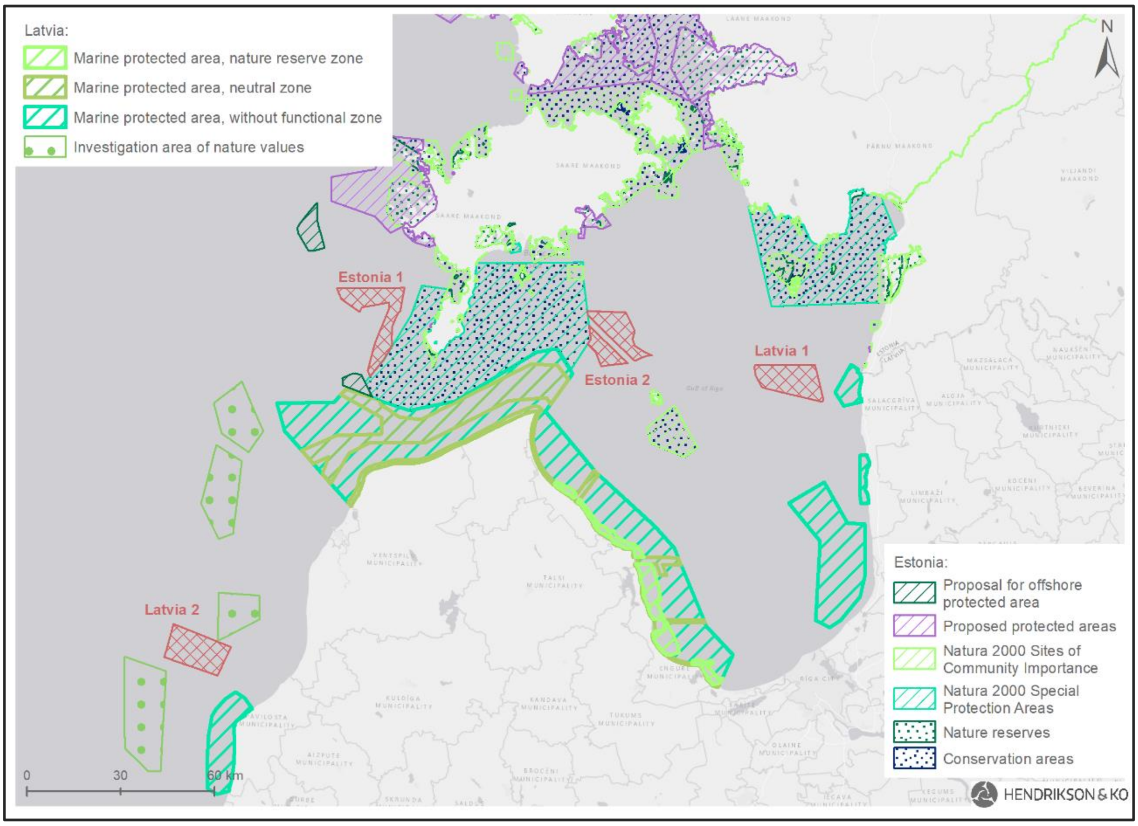
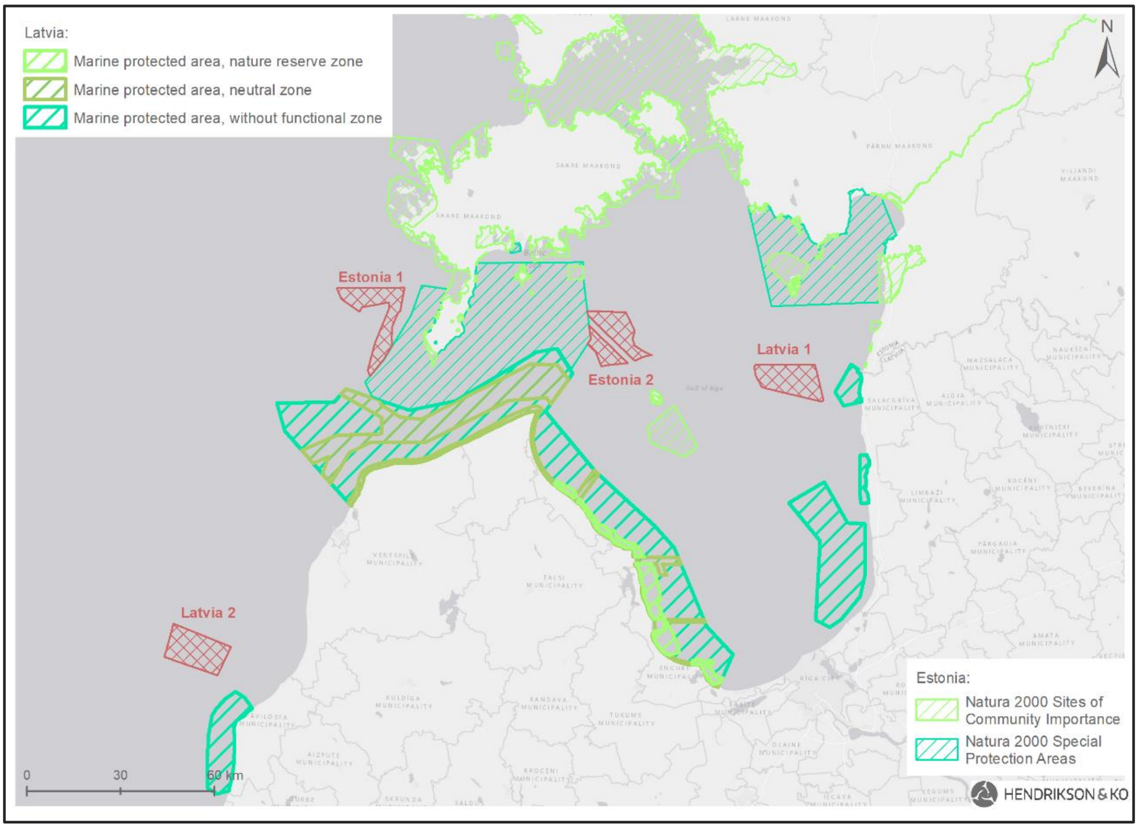


Figure 4.39 Natura 2000 areas



4.15.3 Assessment of wind farm sites

Nature protection and Natura 2000 areas do not overlap with any of the four wind farm sites. Because of possible indirect effects of wind farms located outside of Natura 2000 areas, the proximity of Natura 2000 is further assessed.

Wind farm site Estonia 1 and Estonia 2 are located next to a large Natura 2000 bird protection areas. The Natura 2000 bird protection area between and below Estonia 1 and Estonia 2 are one of the most important stopping places and feeding areas for migratory birds in Estonia and Latvia. As described in paragraph 4.12 wind turbine can have serious impact on birds during the operational phase. Wind farm site Latvia 1 is positioned in the proximity to a small Natura habitat protection area, which is important for different fish species. The possible effects on fish from this Natura 2000 area is only temporary during the construction phase. Latvia 2 is in the proximity of a small Natura 2000 habitat and bird protection area.

4.15.4 Conclusion

All four wind farm sites are located outside of Natura 2000 and other nature protection areas. Wind farm site Estonia 1 and Estonia 2 are located next to a large Natura 2000 bird protection areas. There are no large Natura 2000 area in the direct proximity of wind farm sites Latvia 1 and Latvia 2. However, the Natura 2000 near Latvia 1 is protected only for fish habitats and no bird habitats. Therefore, the effects of Latvia 2 on Natura 2000 are more limited. To conclude, the highest score is given to the wind farm site Latvia 1. Latvia 2 is given a somewhat lower score. Estonia 1 and Estonia 2 are given low scores.

Table 4.32 Scores habit of seals (criterium weight = 4%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	6	6	9	8

4.16 Onshore visual impact

4.16.1 Introduction and methodology

The visibility of wind turbines from the mainland is the most important factor for determining the visual impact. When offshore wind turbines are visible, they can affect the landscape on the shore. In this section we calculate whether, and if so to what extent, wind turbines are visible from the shore for each of the below wind energy areas.

Even when a wind farm is or can be visible from the shore, its impact is dependent on other factors, such as population density and recreation. In a sparsely populated area, the impact will be less since fewer people are affected. At the same time, in a sparsely populated area, a wind farm may be easier to see. A more populated area, in comparison, probably has more buildings or other obstacles blocking the view.

The following characteristics of a wind farm are relevant to determining visibility and impact:

- the number of turbines
  - turbine characteristics
- the distance from the coast
  - weather conditions
  - human eye
- population density on the shore
- nearby cultural values

Number of turbines

Since this is a prefeasibility study, precise coordinates of the turbine positions are not yet available. The same is true for the precise number of wind turbines. Therefore, for this visibility and impact analysis, the outer edges of the wind farm sites are taken as the position for the closest wind turbines, so that the visibility of the wind turbines in the wind farm area cannot be underestimated.

This analysis uses the dimensions of the reference wind turbine as mentioned in paragraph 2.2. These dimensions are repeated below.

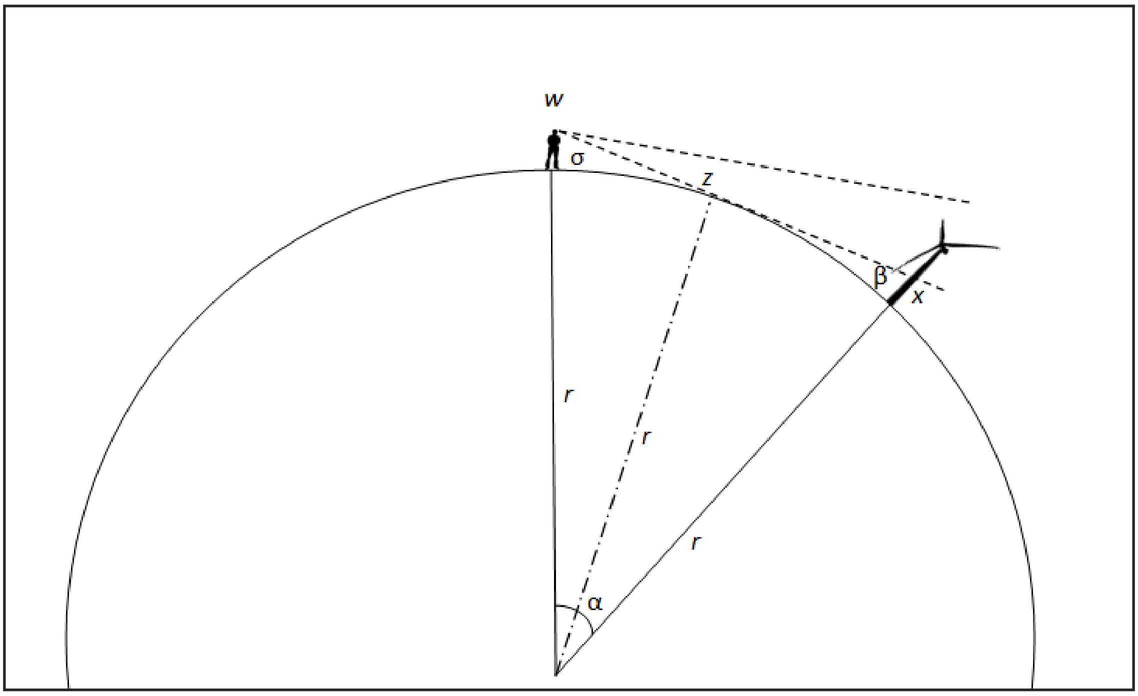
Table 4.33 Turbine characteristics

Characteristic	Meters
Hub height	165
Rotor diameter	275
Tip height	302,5

Distance from the coast

The further an object is from a human's eye, the harder it is to see. Moreover, objects at significant distances away will fall below the horizon line, rendering them invisible in practice (see figure below).

Figure 4.40 Objects further away will be behind the Earth's horizon



These effects must be considered for determining the visibility of offshore wind turbines. Offshore visibility in turn affects the onshore impact. After all, if a turbine cannot be seen from the shore, it cannot have an impact on the landscape. Table 4.34 shows at what distance from the viewer an object disappears from the horizon.

Table 4.34 Objects disappearing behind the Earth's surface

Distance to object	Part of the object below the horizon (measured from eye-level, about 1.6 meters)
10 km	2 meters from the earth's surface
20 km	20 meters from the earth's surface
30 km	50 meters from the earth's surface
40 km	100 meters from the earth's surface
50 km	160 meters from the earth's surface
60 km	245 meters from the earth's surface
70 km	336 meters from the earth's surface

For example: at 40 kilometres to an offshore object, the bottom 100 meters of the object (from the Earth's surface, the sea) would be invisible due to the curvature of the earth. It follows from the above formula that the reference turbine in this report, which has a tip height of 302,5 meters, would be completely invisible at 67 kilometres. The nacelle, which is at 165 meters, would be completely invisible at 50 kilometres.

Weather conditions

The most important factor on offshore wind turbines' visibility, besides their size, are the meteorological conditions. Visibility is often restricted by (water) particles in the air, which reduce the air's permeability and thus the visibility distance. Several Estonian weather posts measure the maximum visibility distance per hour. For this study, we took the average of the reported visibility during average daylight hours (6AM – 6PM). This does not take seasonal effects or daylight savings time into account. By taking the average of the closest weather stations it can be calculated what percentage of the time the wind farm is potentially visible. See Figure 4.41 and Table 4.35.

Figure 4.41 Wind farm sites and weather stations

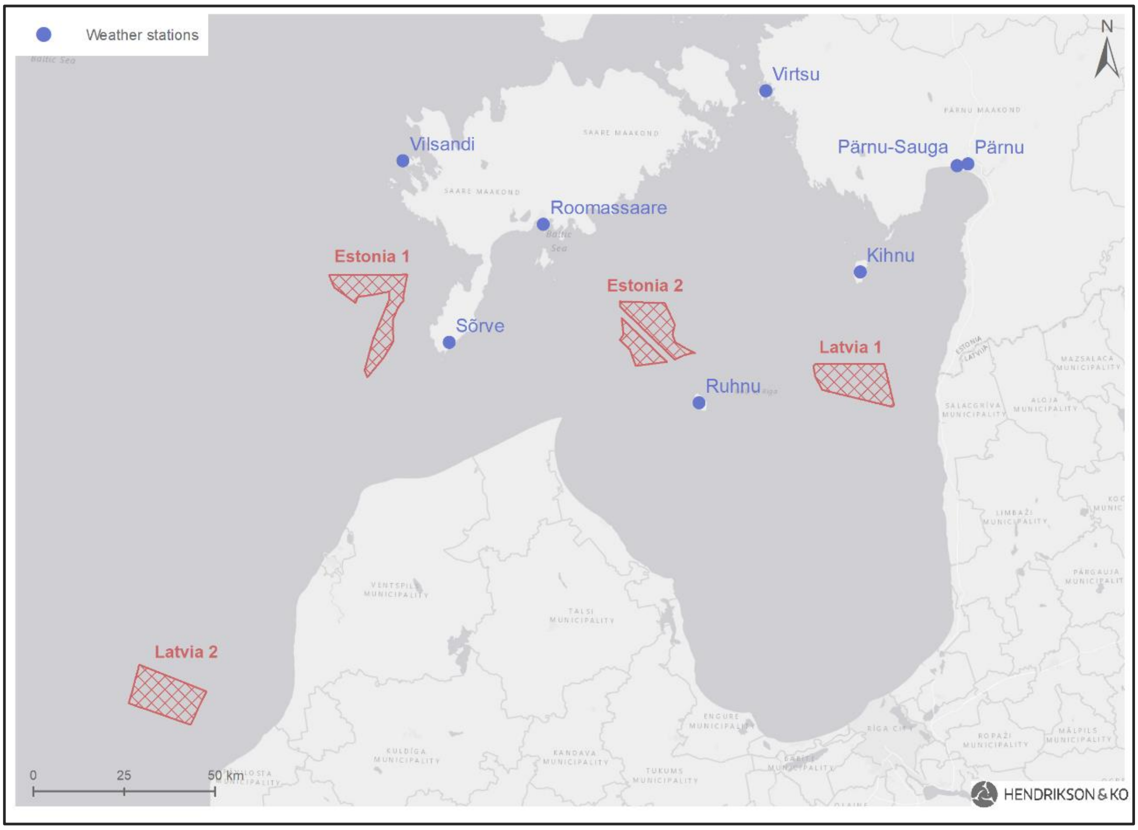


Table 4.35 Weather stations and visibility

Weather station	Max visibility (in kilometres)
Kihnu	27
Roomassaare	20
Ruhnu	28
Pärnu-Sauga	30
Pärnu	26
Virtsu	28
Vilsandi	27
Sõrve	28

For each wind farm site, the closest weather station has an average visibility of 28 kilometres. For Latvia 2, there is no direct data available, so we assume the value to be similar.

The human eye

The human eye is a highly sensitive instrument with a sharp perceptual capacity, but it nevertheless has natural limitations. To determine the maximum range of vision, the visual acuity or "visus" of the human eye must be considered. Scientific literature[33] shows that under optimum conditions (high contrast and good lighting conditions) the human eye of a young and healthy person can distinguish two objects from each other (in the centre of the field of vision) when they are 0.3 arc minutes apart. This means that an object of 1 meter wide is still visible at 10 kilometres. A wind turbine mast with a diameter of 4 meters, for example, can therefore theoretically still be distinguished from the background at 40 kilometres - under optimal conditions.

However, not all parts of the wind turbine have the same size and are therefore still visible at the same distance. We therefore distinguish between the main parts of the turbine, making assumptions about the dimensions of these parts. Table 1.5 shows these dimensions.

Observing wind turbines up to the theoretical sight distance is only possible under the most optimal conditions and will be virtually impossible in practice. To avoid underestimating the landscape effects these numbers were used in this study (worst case estimation).

Table 4.36 Turbine parts, sizes, and their heights*

Turbine part	Part size (meters)	At max height	Max visible distance (human eye)
Tower (max diameter)	10	165	> 100 kilometres
Nacelle	12	177	> 100 kilometres
Blades (max width)	9	210	> 100 kilometres
Blade tip	0,6	302,5	< 10 kilometres

* Extrapolated from current turbine sizes

Research has also been done on the actual performance of the human eye in relation to visibility of wind turbines.[34] This showed that in extremely clear weather, at 25 km, about 25 percent of observers could still recognize an object. This study looked at turbines with an axis height of 50 meters and a rotor diameter of 52 meters. The study shows that large contrast values between the object and its surroundings are particularly important when observing objects.

These insights regarding the vision of the human eye are important when interpreting the visibility of wind turbines at sea. Up to 5 km, the entire rotor blade is visible to humans, and it can be assumed that an average person will be able to perceive this. After that, however, the visibility will decrease because the contrast is not maximum. A white turbine against a blue background is clearly visible, but there is no continuous situation with maximum contrast. Contrast is in fact largely determined by the (weather) conditions, and these are almost never good enough to achieve the maximum theoretical visibility.

[33] Shang, H. and Bishop, I.D., Visual thresholds for detection, recognition, and visual impact in landscape settings, 2000
[34] Bishop, et al, 2002: Determination of thresholds of visual impact: the case of wind turbines

Assessment framework and scores

There are two factors that play into the assessment of the visual impact of each wind farm site. Even when a wind farm area is easily visible from the shore, this does not necessarily mean it has a large impact. In a (relatively) uninhabited area, very few people will regularly see the wind turbines and experience any effects. The population density in the area where wind turbines are visible is crucial in determining the actual impact of a wind farm. The first factor for assessing onshore visual impact is the number of people living within the 'visibility circle' of each wind farm site (more explanation in the next paragraph). Using a GIS-model, the mean population within the 'visibility circle' of each wind farm site will be calculated.

The second is the number of recreational places (beaches, wind surfing sites, etc.) and culturally significant locations on shore that are within the visibility circle as defined in the next paragraph.

4.16.2 Data overview and description

Datasets for onshore visual assessment originate mainly from the Maritime Spatial Plan source data packages. Estonian and Latvian population data comes from the Statistics Estonia and Latvian Statistics Portal. Socio-Cultural data layer for Estonia is developed by Hendrikson & Ko and Latvian data was provided by the Ministry of Environmental Protection and Regional Development Republic of Latvia. Offshore visibility data was contributed by the Estonian Environmental Agency.

As discussed in the introduction for this criterium, each wind farm site's border is taken as a starting point for calculations. Visibility from the shore, based on the curvature on the Earth, is calculated based on this point, which ensures a 'worst-case' analysis. For weather conditions and visibility calculations, data from several surrounding weather stations is used. We can estimate the relative impact of each wind area site by analysing the number of people living in this 'visibility circle' (see Figure 4.42).

As the line of sight onshore is quickly blocked by trees, buildings, and other obstacles, only the population living within 1 kilometre from the shore is counted. The same is true for tourism and sociocultural values.

The available Latvian data is defined as population density (population per square kilometre). To convert this number to an approximate number of people, the size of the overlapping part of the circle (in square kilometres) was multiplied by the population density.

The Latvia 2 data only consists of data provided by the Latvian ministries, whereas multiple data sources could be combined for the other three sites.

Figure 4.42 “Visibility circles” and population data

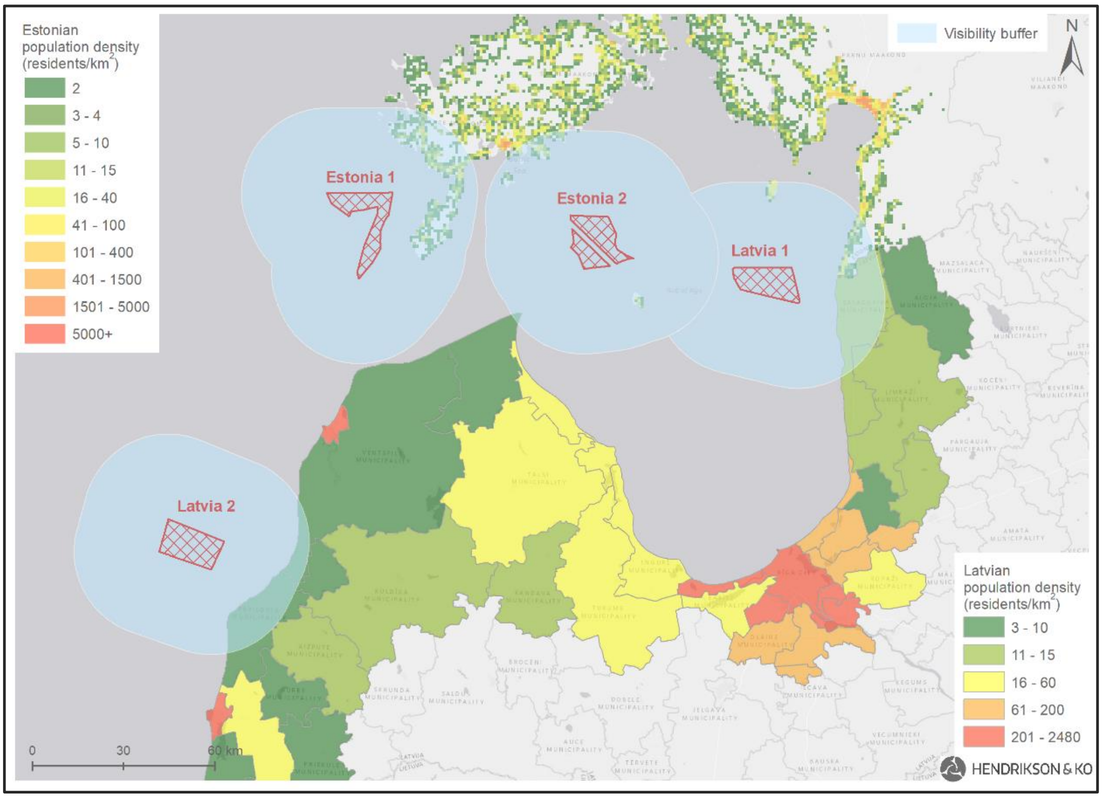
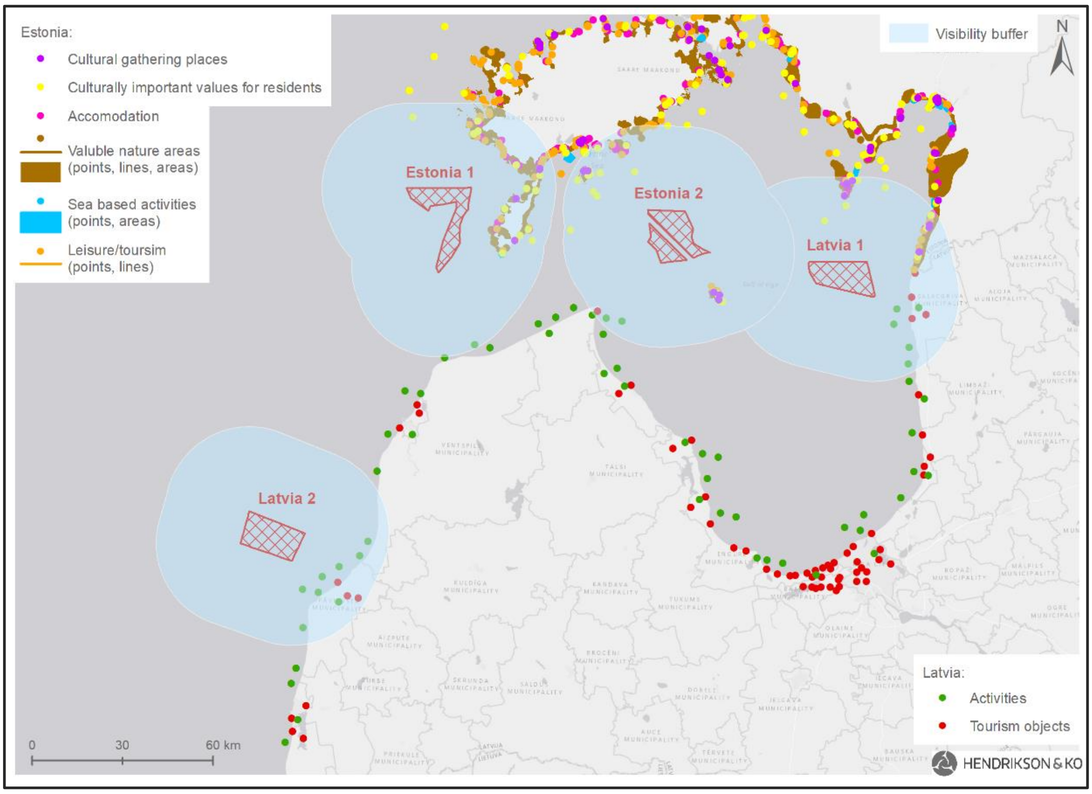


Figure 4.43 Tourism and sociocultural values



4.16.3 Assessment of wind farm sites

Table 4.37 shows the maximum visible distance for each wind farm site, based on the different calculation methods discussed above. The curvature and human eye visibility will be the same for each wind farm site, as the same reference turbine is assumed for all wind farm sites. As discussed above, weather conditions and maximum visibility around the Baltic Sea are very similar. A maximum weather visibility of 28 kilometres is assumed for all wind farm sites. It must be noted that the below scores are based on a reference wind turbine. If a larger or smaller turbine is used, these numbers will change.

Table 4.37 Maximum visible distance for each wind farm site

Wind farm site	**Curvature visibility**	**Weather visibility**	**Eye visibility**	**Affected population**			**Social and cultural values**
				Estonia	Latvia	Total	
Estonia 1	67 km (tip) 50 km (nacelle)	28 km	> 100 km < 10 km (blade tip)	1645	0	1645	High
Estonia 2	67 km (tip) 50 km (nacelle)	28 km	> 100 km < 10 km (blade tip)	684	35	719	High
Latvia 1	67 km (tip) 50 km (nacelle)	28 km	> 100 km < 10 km (blade tip)	1597	2241	3838	Medium
Latvia 2	67 km (tip) 50 km (nacelle)	28 km	> 100 km < 10 km (blade tip)	0	549	549	Low

Estonia 1
Estonia 1 will in general only be visible from the southwestern part of the island of Saaremaa. The distance to Kuressaare is most likely too great to be visible from the settlement. There are approximately 1645 people living within seeing distance of the wind farm site, all of them in Estonia.

The shore on the southwestern part of the island of Saaremaa has relatively many tourist spots within the visible distance of Estonia 1.

Estonia 2
Estonia 2 will generally be visible both from the south-eastern part of the island of Saaremaa, and from the island of Ruhnu. Kuressaare is not within the calculated average visibility distance, but it is possible that the wind farm is visible on very clear days. Moreover, the wind farm may be visible from the northern tip of Talsu. There are approximately 719 people living within the seeing distance of this wind farm site, of which 35 are in Latvia.

The shore on the eastern part of the island of Saaremaa has relatively many tourist spots within the visible distance of Estonia 2. However, the island of Ruhnu is complete within the visible circle.

Latvia 1
This wind farm site is closest to the shore and can be easily seen both from Estonia and Latvia. In Estonia, this is mostly in the southern part of Pärnumaa region (around Häädemeeste and Ikla). In Latvia, the wind site is probably visible from the northern part of Limbazu, most notably from

Salacgrīva. This site has the most people living within a visible distance: 1597 from Estonia and 2241 from Latvia.

The shores of Pärnu Maakond and the Vidzeme region are within the visible distance of Latvia 1. There are relatively many of interest in the visible zone, especially on the island of Kihnu.

The western coast of the Liepajas region has several spots for water sport activities, but otherwise there are relatively few tourist spots based on the current data.

Latvia 2

Latvia 2 is the only wind farm site not visible from Estonia. It will probably be visible from the coast of Ventspils and Liepajas region. The site will most likely not be visible from the town of Ventspils. There are 549 people living within visible distance.

4.16.4 Mitigating measures

There are very few options for reducing the visibility of wind turbines during the day. The construction colour schemes are already grey. Moreover, wind turbines simply are large structures that can be seen from a distance. During the night, the International Aviation Organization (ICAO) recommends using flashing red lights on (offshore) obstacles. If these lights have a significant impact, this could be mitigated by reducing the light intensity and/or using a steadily burning light instead of flashing lights.[35]

4.16.5 Conclusion

The total number of people living within visible distance is quite low, which means that the onshore visual impact is also quite low. However, tourist spots that may attract many more people are also within visible distance of each wind farm site, and especially Estonia 1 and Estonia 2 have many points of interest close by. As the Latvia 2 wind farm site does not have enough data to be assessed to the same level as the other wind farm sites, a slightly lower grade is given compared to Latvia 1.

Figure 4.44 Scores onshore visual impact (criterium weight = 1%)

Wind farm site	Estonia 1	Estonia 2	Latvia 1	Latvia 2
Score	7	7	9	8

[35] ICAO Annex 14, Aerodromes, Volume 1 Aerodrome Design and Operations, Fourth Edition, July 2004.

PONDERA

5 Conclusion

5.1 Final scores

Table 5.1 shows each criterium with its score (on a scale from 1 to 10) and the weighted score, based on the score weights that were provided by the client. The cumulative weighted score is 65.

The allotted scores and assessments in this study were made at a pre-feasibility level of detail. This means that, even though each score is based on expert judgement, scientific literature, and official data, further and more in-depth research is likely to change at least some of the scores below.

Moreover, many of the criteria below have some overlap or interdependency with at least another criterium. A table such as the one below might suggest that each criterium score can be judged in isolation, but each one is in fact dependent on many factors that can also influence other criteria.

Finally, in the final score row we sum the scores of each criterium. These scores are, however, not made in perfectly comparable assessment frameworks, partly due to the limited detail levels of this study. While the weights that are used in this assessment table were carefully thought out and provided by the client, the importance might change. A single criterium might turn out to be more important than previously thought, and a change of criterium weight could change the final scores for each wind farm site.

Table 5.1 Final score table

Wind farm site	**Weight**	**Estonia 1**		**Estonia 2**		**Latvia 1**		**Latvia 2**	
		Score	Weighted score	Score	Weighted score	Score	Weighted score	Score	Weighted score
Icing conditions	8%	7	0,56	4	0,32	4	0,32	8	0,64
Water depth	5%	8	0,40	8	0,40	8	0,40	5	0,25
Waves and currents	5%	10	0,50	10	0,50	10	0,50	10	0,50
Soil conditions	7%	4	0,28	5	0,35	3	0,21	6	0,42
Wind Speed & Capacity factor	9%	10	0,90	10	0,90	8	0,72	10	0,90
Foundation options	2%	7	0,14	5	0,10	4	0,08	7	0,14
Ports	2%	8	0,16	8	0,16	8	0,16	8	0,16
Defence restriction, surveillance & communication, and air traffic disturbance	5%	9	0,45	3	0,15	6	0,30	4	0,20
Shipping routes	1%	7	0,07	8	0,08	9	0,09	9	0,09
Additional capacities / impact on other parks	2%	7	0,14	7	0,14	7	0,14	8	0,16

Wind farm site	Weight	Estonia 1		Estonia 2		Latvia 1		Latvia 2	
		Score	Weighted score	Score	Weighted score	Score	Weighted score	Score	Weighted score
Fisheries and impact on fish	2%	8	0,16	8	0,16	8	0,16	8	0,16
Birds	4%	7	0,28	7	0,28	7	0,28	7	0,28
Bats	4%	7	0,28	7	0,28	7	0,28	7	0,28
Seals	4%	8	0,32	4	0,16	4	0,16	8	0,32
Nature protection areas	4%	6	0,24	6	0,24	9	0,36	8	0,32
Onshore visual impact	1%	7	0,07	7	0,07	9	0,09	9	0,09
Total	**65%**	120	**4,95**	108	**4,29**	111	**4,25**	121	**4,91**

5.2 Final conclusions and recommendations

Based on the weights provided by the client and the assessments made in this study, wind farm site Estonia 1 receives the highest weighted score, followed closely by Latvia 2 with a weighted difference of only 0,04 points. Estonia 2 and Latvia 1 are separated by the same weighted difference, with Latvia 1 getting the lowest score of the four wind area sites.

Identified opportunities and challenges

Based on the information available in this study all four wind farm sites are feasible. No significant barriers are identified which limit the further development of wind energy in the wind farm sites in this stage. Hence, no wind farm sites are given zero points for a specific criterion. The wind speed and estimated electricity production for all four wind farm sites offers a good basis for a positive business case. The wind speed at hub height (165m) varies between 9,5 and 9,8 m/s. In this study, however, various challenges for wind energy at the wind farm sites have been identified. Further research should be executed to provide a better understanding of the potential risks and significance for the further development. The main identified challenges for wind energy in this study are listed in the table below.

Based on the available data, the other criteria pose no significant impacts on the further development of wind energy in the wind farm sites. However, more research is needed to identify the effects of the wind farms on the bird and bat migration routes and its significance. Ecological effects could also be mitigated to reduce the impact, examples are effects on birds, bats, seals, and fish.

Table 5.2 Main identified challenges ELWIND

Main challenges	Description wind farm sites	Impact
Ice conditions	Lower ice coverage and thickness is expected in Estonia 1 and Latvia 2 compared to Estonia 2 and Latvia 1.	Necessity of designing larger, heavier, or stiffer foundation types or even the exclusion of certain foundation types (e.g. floating wind and conventional monopiles). In general, GBS and jackets are better able to cope with ice conditions compared to monopiles.
Water depth	Estonia 1, Estonia 2, Latvia 1 and the eastern part of Latvia 2 have comparable and feasible water depths for wind energy (17 – 45 m). Latvia 2 however includes an area (approximately 40 percent of the total wind farm site) with a water depth above 45 meters and up to 60 meters.	Limiting the foundations options (for example conventional monopiles and GBS) and increasing the development costs for Latvia 2.
Weak seabed conditions	High likelihood of weak seabed conditions (mud/clay) in the top layers is identified for Estonia 1, Estonia 2, and Latvia 1.	Impacts the stability of especially GBS and to a lesser extent suctions buckets. It also increases complexity with drilling methods.
Stone layers	High likelihood of deeper stone layers (limestone, sandstone, carbonate) is identified for all four wind farm sites.	Impacts the possibility to use driven pile monopiles and jackets
Height restrictions	Height restrictions from defence radar systems for all four wind farm sites, except Estonia 1. Height restrictions ranges from 131 to 400 meters.	Impacts the business case of the wind farm

Foundations options

The identified ice, water depth and soil conditions can result in the necessity of designing larger, heavier, or stiffer foundation types. This possibly creates additional construction complexity and costs and could have a significant impact on the further development of wind turbines in the four wind farm sites. Moreover, some wind turbine foundation types can be excluded in the wind farm sites, like floating wind, conventional driven pile and small monopiles, and standard GBS structures. However, more innovative, and complex foundation types and construction methods are still available for all four wind farm sites and their site-specific conditions. Examples are:

- floating GBS;
- suction buckets;
- jackets with shorter piles;
- XXL monopiles that does not include pile driving, like drilling.

The feasibility of these foundations options highly depends on the bearing capacity of the top layer of the seabed and the presence, depth, and strength of the deeper stone layers. Eventually, the most feasible foundation type and construction method should be engineered based on the exact site-specific conditions, including soil conditions, water depth and ice conditions.

Most feasible wind farm sites

Based on the final scores, the main identified opportunities, challenges and foundations options, the most feasible wind farm sites are Estonia 1 and Latvia 2.

The main reasons why wind farm site Estonia 1 is the most feasible are:

- Lower water depth
- Relatively limited ice conditions
- Relatively good foundation options
- No identified defence and height restrictions
- Relatively low impact on seals
- Good wind climate

The main reasons why wind farm site Latvia 2 is the most feasible are:

- Relatively limited ice conditions
- Relatively good foundation options
- High likelihood of good top seabed conditions with sand and coarse-grained sediment
- Relatively low impact on seals
- Good wind climate
- 60 percent of the wind farm site still has a water depth lower than 45 meters. If only 60 percent of the wind farm site is used for wind energy, the target of 700 - 1000 MW could still be reached.

Recommendations for further research

An important point of attention for wind energy in Estonia 1 is the bearing capacity of the top seabed layer. For both Estonia 1 and Latvia 2 the presence and strength of the deeper stone layers is an important point of attention. Therefore, geophysical and geotechnical surveys are to be executed to provide a better understanding of the soil conditions. This is especially important to engineer the most efficient foundation type and construction method.

For Latvia 2 the impact on the Latvian navigational radar and possible mitigating measures should be further investigated. The effects on radar could possibly be mitigated by constructing a supporting radar or new radar system or researching the actual effect of the wind farm on radar reception and optimizing the wind farm lay-out.

For all offshore wind farm developments additional ecological research should be executed. This ecological research should include research on the presence of birds and bats and modelling of collisions, disturbance, and barrier effects. Also, the effects on (ringed and grey) seals, under water life (benthos) and Natura 2000 in general should be examined.

Other surveys that should be considered includes an archaeological survey, unexploded ordnance survey, morphodynamical study and a wind resource assessment.

Finally, the grid connection is a major aspect of the development of offshore wind energy and contributes largely to the total costs of the project. The grid operators and governments of Estonia and Latvia are currently investigating the various possibilities of not only connecting a potential wind farm to the mainland grid, but also creating an interconnection between the two countries. In this feasibility study a general overview of implications and focus points for the construction of a cable connection to the wind farm is indicated for each criterium where relevant.