Hesselø Offshore Wind Farm

Radar and radio interference
Technical report

Energinet Eltransmission A/S

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Contents

1 Summary (in Danish)

Denne rapport er udarbejdet som et bidrag til en senere miljøkonsekvensvurdering af Hesselø Havvindmøllepark, som planlægges at blive placeret centralt i Kattegat indenfor et 247 km^2 stort område beliggende ca. 30 km nordvest for Gilleleje og 45 km øst for Grenå. Formålet med denne rapport er at kortlægge og beskrive eksisterende, civile radaranlæg og radiokæder samt at vurdere konsekvensen for disse som følge af anlæg, drift og afvikling af Hesselø Havvindmøllepark.

Ifølge eksisterende og tilgængelig viden og informationer er der ingen indikationer på, at de lufthavne, som er placeret tættest på Hesselø Havvindmøllepark, vil blive kritisk berørt under anlæg, drift og afvikling af Hesselø Havvindmøllepark på grund af den store afstand mellem lufthavnene og det planlagte område for parken. Dette er også gældende for de civile radarer, der bruges til at overvåge lufttrafikken i Danmark. Skibsradarer forventes heller ikke at blive berørt af etableringen af Hesselø Havvindmøllepark, eftersom både radarer og visuelle markeringer vil vise placeringen af møller. Derudover vil tilstedeværelsen af havvindmølleparken fremgå af kort for både luft- og skibstrafik. Af de fem meteorologiske radarer i Danmark, som er administreret af Dansk Meteorologisk Institut (DMI), forventes ingen at blive berørt af etableringen af Hesselø Havvindmøllepark. I forhold til radiokæder findes ingen punkt-til-punkt tilladelser for radiokæder i planområdet for Hesselø Havvindmøllepark.

Militære radarer er ikke inkluderet i denne rapport. Den omhandler alene civile systemer.

Flere danske og svenske havvindmølleparker planlægges at blive etableret i Kattegat i løbet af det næste årti, men eventuelle kumulative effekter på radarer og radiokæder som følge af disse forventes enten at være ubetydelige eller at blive afværget.

Konklusionerne i denne rapport er baseret på en overordnet plan for Hesselø Havvindmøllepark, som indeholder flere forskellige scenarier og udformninger, og typen, varigheden og omfanget af konsekvenserne for radarer og radiokæder som følge af anlæg, drift og afvikling af Hesselø Havvindmøllepark kan først endeligt vurderes i den fremtidige miljøkonsekvensrapport, når det specifikke projekt er blevet fastlagt.

2 Introduction and aim

With the Energy Agreement in June 2018 and the following 'Climate agreement for energy and industry, etc. 2020' in June 2020, the Danish parliament decided to tender for a new offshore wind farm of 800 – 1,200 MW with grid connection in 2027. The offshore wind farm will be located in the central Kattegat approx. 30 km north of Gilbjerg Hoved on the north coast of Zealand. The wind farm is named Hesselø Offshore Wind Farm (Hesselø OWF) after the small uninhabited island of Hesselø, which is located southwest of the area. The Hesselø OWF will have an installed capacity of minimum 800 MW and maximum 1,200 MW.

The planning area for Hesselø OWF is shown in Figure 2.1.

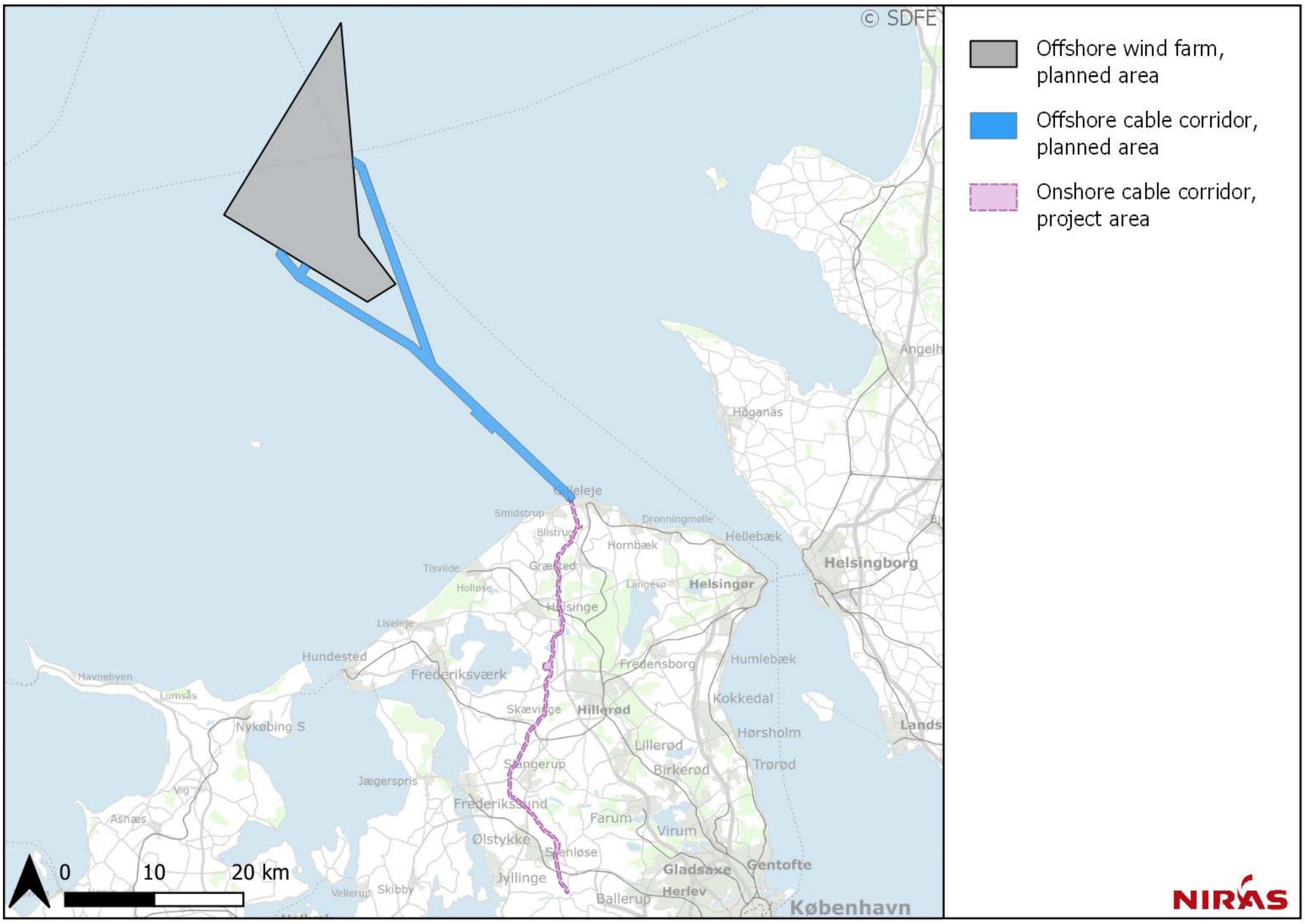

Figure 2.1: Planning area for Hesselø Offshore Wind Farm.

In order to ensure that Hesselø OWF will be supplying electricity by 2027, the Minister of Climate, Energy and Utilities has instructed Energinet to initiate the preliminary studies for the project – both offshore and onshore. This includes strategic environmental assessment (SEA) of the plan for the overall project, completion of relevant environmental surveys etc., investigation of a grid connection from the coast to the connection point at Hovegaard High Voltage station and preparation of an environmental impact report (EIA) for the onshore facilities.

The location of Hesselø OWF is based on a detailed screening of multiple areas for offshore wind farms in Danish waters carried out for the Danish Energy Agency and reported in spring 2020 (COWI, 2020).

The plan for Hesselø OWF is described in a memorandum from the Danish Energy Agency (Energistyrelsen, 2021a) and in the scoping report for the environmental assessment of the plan (Energistyrelsen, 2021b), which was issued in connection with the first public consultation (February 12th to March 19th 2021).

2.1 Aim

This report describes the consequences for civil radar systems and radio chains as well as aviation facilities in relation to the plan for Hesselø Offshore Wind Farm. The first section of the report presents the plan for Hesselø OWF including a description of project scenarios following a method description for the assessment of effects on civil radar systems and radio chains. A brief introduction to the main principles of radar systems and radio chains is followed by a short description of relevant national and international guidelines and practices. A description of the relevant legislation is also included where applicable. The report presents baseline descriptions of existing radar and radio chains that may be affected by the establishment of Hesselø OWF based on available data and information. Based on this, the report comprises an assessment of the potential effects of Hesselø OWF on the functioning of radar systems and radio chains, in relation to construction and operation, followed by proposals for mitigation measures. Potential effects in relation to decommission of Hesselø OWF is not considered since it is estimated that the type and duration of effects on radar systems, aviation facilities and radio chains will correspond to the effects described and assessed for the construction phase. Cumulative effects of other wind farms as well as possible data gaps and insufficiencies are described in the last section of the report. This report has been prepared by NIRAS and Integra for Energinet in connection with the planned establishment of Hesselø OWF.

3 Method and surveys

Experience from other offshore wind farms shows that radars, aviation facilities and radio chains can be affected mainly by shadow effects and reflections from offshore wind turbines. Offshore wind turbines can affect ship- and land-based radar systems as well as radars used to monitor air traffic. The reason for the interference is the structures of the turbines, the heights of the turbines and the rotor movements, which can reflect the radar signals. In addition, the signals for telecommunications and data transmission may be impaired if the offshore wind turbines are placed in Line Of Sight (LOS) for radio chains or within respect areas of aviation facilities.

In this report, a study is carried out for radar systems used for maritime and aviation purposes, as well as other aviation facilities and radio chains used for telecommunication and data transmission in the area around Hesselø OWF.

The description of the existing baseline conditions has been completed by collecting data regarding radar systems and radio chains from the Danish Energy Agency's frequency register (Frekvensregisteret) using accompanying guidelines (Energistyrelsen), Retsinfo, the Danish Meteorological Institute, the Danish Aeronautical Information Publication (AIP) and the Danish Business Authority (kort.plandata.dk). Information in relation to Swedish airports has been retrieved from the Swedish AIP (AROWeb) and the Swedish Transport Agency (Trafikverket, 2021).

The assessment of the potential effects on radar systems and radar chains in relation to the establishment of Hesselø OWF is based on the possible scenarios described in section 3.1.

3.1 Scenarios for Hesselø Offshore Wind Farm

In the order to Energinet, the Minister of Climate, Energy and Utilities has instructed Energinet to initiate a series of preliminary studies for the offshore part of the project. The results of the studies will be provided to the tenderes for the offshore wind farm and will form important input for the environmental impact assessment of the specific project. To ensure that the studies have the right focus and are relevant for an offshore wind farm (anno 2027) of 800 – 1,200 MW, a set of key technical parameters has been considered and a number of scenarios have been developed. The key technical parameters and scenarios listed in Table 3.1 are used in relation to the assessment in this report.

Wind turbines with a capacity in the range of 8-20 MW is the base of the assessment. The minimum turbine capacity of 8 MW corresponds to the installation of up to 150 turbines, and the maximum turbine capacity of 20 MW corresponds to the installation of up to 60 turbines. A grid of inter-array cables (66kV) installed in the seabed will connect the individual turbines to the offshore transformer platform, which will connect the wind farm to the onshore grid via 2-3 export cables also installed in the seabed.

The parts of the project located on land are described in the technical project description that forms the basis for the environmental impact assessment of the project on land.

The layout of the offshore wind farm and turbines is not decided at present, as this will be determined by the future Concessionaire. The current assessments have therefore been made at an overall level, taking into account the different variations regarding total installed capacity, sizes of turbines and the consequent difference in the number of turbines and layouts of Hesselø OWF. For each of the turbine sizes (8 MW, 15 MW and 20 MW) specific layouts have been developed to support the visualizations and other parts of the assessment. An environmental impact assessment will be prepared for the specific offshore project by the Concessionaire.

Table 3.1: Technical parameters for the scenarios for Hesselø OWF included in this report.

Technical parameters			
Offshore wind turbines			
	8 MW turbine	15 MW turbine	20 MW turbine
No. of WTGs	100 - 150	54 - 80	40 - 60
Rotor diameter, meter	170	260	280
Hub height, meter	105	150	170
Tip height, meter	190	280	310
Nacelle (length, width, height), meter	20x8x8	29x13x13	32x15x15
Fundaments			
Monopile diameter, meter	10	13	15
Pile driving; hammer size, blow strength and blow rate	IHC S-4000, 6000kJ, 7000 blows. Rate: 4 seconds for 'soft start-procedure' thereafter 2 seconds.		
Scour protection	15 – 20 meter in diameter		
Offshore transformer platform*			
Dimensions (length/width), meter	40/25		
Inter array cables			
	66 kV	66 kV	66 kV
Export cables			
No. of cables	2-3		
Voltage level	220 kV – 345 kV (AC)		
Investigated cable corridor (offshore), meter	1.000		
Distance between cables in Natura 2000 sites/other areas, meter	50/150-200		
Depth of cable trench, centimeter	60-100		
Length of directional drilling (at landfall), meter	Up to 1,000		

* One platform is expected to be established, but two possible locations are included in the preliminary investigations and in the strategic environmental assessment.

3.2 Legal requirements and regulation

This report only concerns civil radar systems and radio chains and potential effects on these in relation to the establishment of Hesselø OWF. Therefore, legislation and regulation is only considered in relation to civil radar systems and radio chains.

3.2.1 Radar systems

It is required that certain types and sizes of aircraft and ships must have radar for navigation, identification and anti-collision systems, among others (BEK nr. 9848 af 12/04/2007), and therefore it is relevant to assess whether these radar systems are affected by the establishment of an offshore wind farm.

3.2.2 Radio chains

Current legislation in relation to radio chains can be found in the Executive Order on the Radio Frequencies Act from 2016 (LBK nr. 1100 af 10/08/2016), which among others regulates how to apply for permission to use radio frequencies. There is no legislation that regulates radio chains against interference, and if an offshore wind farm causes effects on radio chain links that require mitigation, a dialogue must be initiated between the concessionaire and the owner of the radio chain. If the parties cannot agree on a solution, it will ultimately be solved in court.

4 Baseline description

4.1 Radars

Radars (RAdio Detection And Ranging) are mainly used by airports, air traffic control centers, meteorological services and ships as well as the Danish Defence for surveillance of airspace and sea areas.

Wind turbines represent a high risk of disturbing electronic devices, as the turbines may shadow for and/or reflect radio waves. In this section the most important types of radar equipment are introduced, and radar systems and radio chains in proximity to the planned area of Hesselø OWF are described, as they may potentially be affected by the establishment of the wind farm.

There are two basic forms for radar equipment, which are normally described as primary and secondary radar.
The primary radar works in such a way that a direction-controlled radar antenna sends a short radio signal and afterwards receives the reflected signals from all objects the radio signal meets. The received signals may thereafter be displayed on a radar screen for the operator, e.g. the air traffic controller in the airport or the captain of the ship. A wind turbine is usually easily displayed on the primary radar screen for the operator as the tower and the wings of the wind turbine may give reflections of the primary radar signal.

The secondary radar works by sending direction-controlled coded signals out from the radar antenna. This signal will trigger a transponder onboard the aircraft or ship, which replies by sending a coded signal back to the radar antenna containing information about for example the height of the aircraft. The coded signal will be processed and displayed on the radar screen with detailed information of the aircraft or ship.

Both the primary and secondary radar coverage are limited by the design of the system and most importantly whether there is direct sight between the radar antenna and e.g. the aircraft or ship. Direct sight is called "line of sight" (LOS). Limitations of LOS may be obstacles such as buildings and terrain which shadows the radar signal, but also wind farms may reduce the radar coverage as the wind turbines may shadow for radar signals. In addition to this, turbines and buildings may reflect signals in unwanted directions and give false markings on the radar screen for the operator.

An important obstacle, which should always be assessed for the radar coverage, is the curvature of the earth, as both primary and secondary radars must have LOS with the objects they surveil. The two types of radars cannot see below the horizon, here called Radar-Horizon. A simple rule of thumb for estimating the radar coverage for an object in relation to the curvature of the earth can be applied with this simple formular:

Radar coverage in NM (nautical mile) = 1.23 * sqrt (object height in feet)

Considering the 'worst case' scenario with the largest 20 MW turbine suggested for Hesselø OWF, a tip height of 310 m (approx. 1018 feet) will correspond to the turbine being just below the radar coverage approx. 39 NM (approx. 73 km) from the radar. However as mentioned above, other factors may reduce radar coverage such as shadow effect from terrain and buildings, but height of the radar antenna and the type of radar may increase the distance to the Radar-Horizon. Radar antennas are therefore often placed on high terrain and/or on a high mast, in order to increase the distance to the Radar-Horizon.

4.1.1 Military radar systems

Radars are used by the Danish Defence to monitor Danish waters and airspace. This operation is done and coordinated by Joint Operations Centre (JOC) (Forsvarets Operationscenter).

Potential effects on military radar systems is not part of this study, and baseline in relation to military radars is thus not considered here.

4.1.2 Air traffic radars

Safety zones for radars used for Danish civil air traffic control is shown on the Danish Business Authority's webpage ('respect distance for installation and construction'). Hesselø OWF is situated far away from any Danish civil radars' safety zone. The only civil Danish radar which may be within LOS of Hesselø OWF is placed in Aarhus Airport (Naviair, 2020). The radar is a secondary radar (MSSR) which has a coverage up to 250 NM.

4.1.3 Aviation facilities

Air traffic may operate visually, as it is the responsibility of the aircraft to ensure separation to other air traffic and obstructions by visually maneuvering to prevent collision: "See and avoid". These types of flights are following visual flight rules (VFR). It is typically smaller aircrafts and e.g. helicopters, which fly after these rules.

Larger aircrafts, e.g. airlines, are normally following instrument flight rules (IFR). They ensure prevention of colliding with obstacles such as wind farms by routing the air traffic around of the obstacle at a safe distance or by allowing the traffic in a safe altitude above the obstacle. This safe altitude is called Minimum Safe Altitude (MSA) and is normally 1000 feet, which is around 300 m, above the obstacle. The MSA must always be marked on relevant flight maps used by air traffic. For Swedish civil airports, MSA surfaces extend up to 55 km from the airport (Trafikverket, 2014).

Airports are safeguarded by obstacle limitation surfaces (OLS) to protect the air traffic to/from the airport from colliding with obstacles. These surfaces must generally not be penetrated by obstacles such as wind turbines. The size of these surfaces depends upon the size of the airport and may extend up to 15-20 km from the airport and is often regulated by land registers. In addition to these surfaces, consultant zones and protection zones for other aviation facilities extend up to 60 km from Danish airports (Erhvervsstyrelsen, 2018).

There are three larger airports and one small public aerodrome close to Hesselø OWF (Figure 4.1). The larger airports with instrument landing facilities are Aarhus Airport situated in Denmark, and Halmstad and Ängelholm-Helsingborg Airports situated in Sweden. These airports are located approx. 65, 57 and 55 km from Hesselø OWF, respectively. Because these three airports have instrument procedures, it must be assessed if there is any influence of Hesselø OWF on the safeguarded surfaces, radio facilities, instrument procedures and consultant zones of these three airports.

On the island of Anholt there is a small public aerodrome approx. 22 km north-northwest of Hesselø OWF. There are no instrument procedures to Anholt aerodrome and therefore only the safeguarded surfaces should be assessed.

4.1.4 Ship radars

Both commercial ships and pleasure crafts use mobile radar systems for navigation in order to avoid collisions. The radar systems are especially important for navigation in weather conditions with low visibility. Since the planning area for Hesselø OWF is located in the central Kattegat, the turbines represent a potential hazard for ship traffic in the area with respect to collision. The primary radar onboard a ship is therefore an important instrument in avoiding collision.

Information on maritime traffic and the safety of navigation in central Kattegat in relation to establishment of Hesselø OWF is provided in the technical report on this issue (DNV, 2021). Generally, the collision risk is reduced and controlled through regulation, as offshore wind farms must be marked with obstruction lights and specific painting, so they become visible both day and night. This ensures that the turbines are visible for ship traffic. In addition to this, the wind farms must also be displayed on relevant maps.

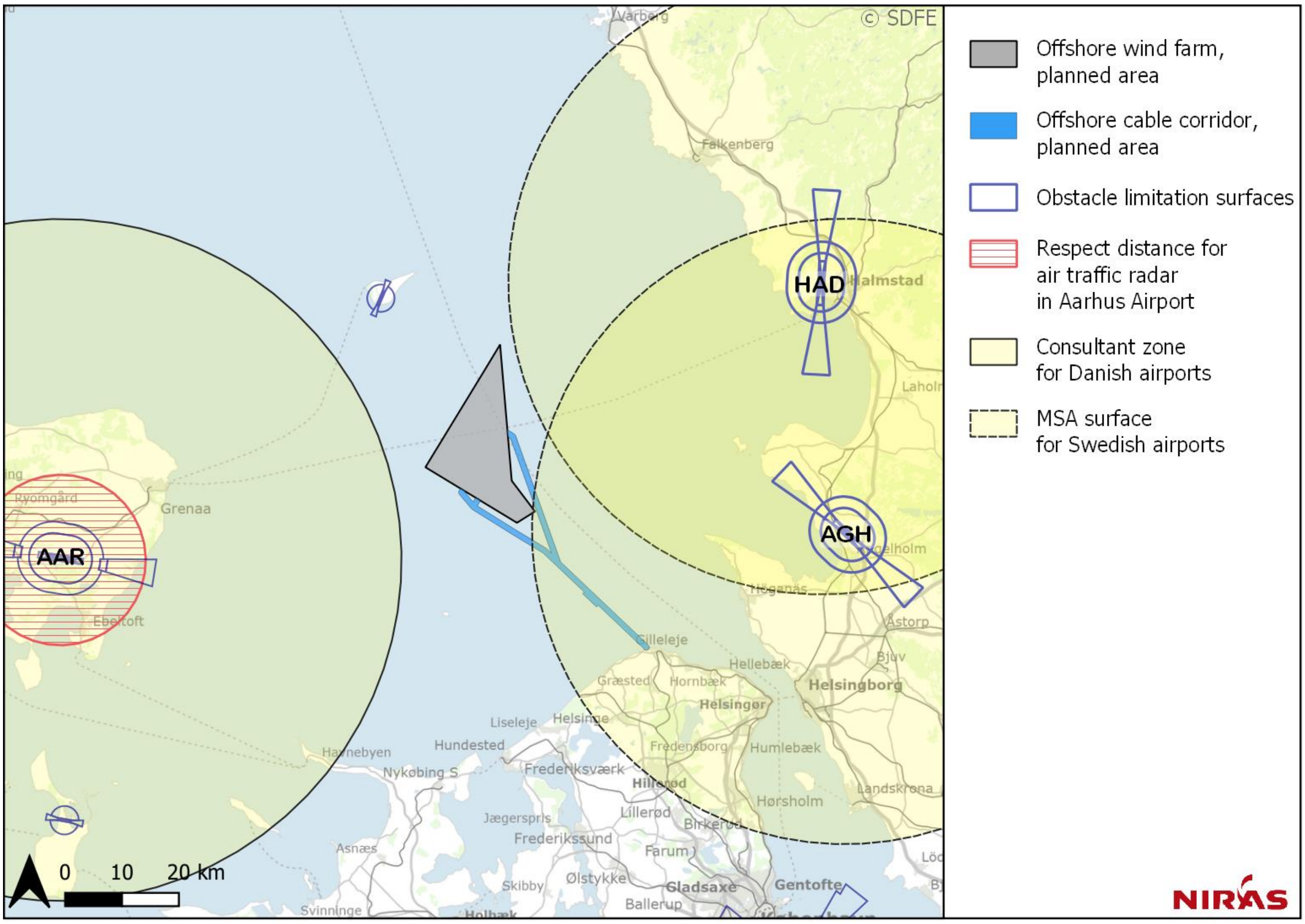

Figure 4.1: Illustrative figure displaying airports in proximity to the planned area for Hesselø OWF. Obstacle limitaion surfaces, respect distances, consultant zones and MSA surfaces are shown for the three larger airports, Aarhus (AAR), Halmstad (HAD) and Ängelholm-Helsingborg (AGH). In addition, OLS are shown for a small, public aerodrome is located on the island of Anholt.

4.1.5 Meteorological radars

Offshore wind farms located near meteorological radars can give rise to false echoes that can be misinterpreted as weather phenomena such as precipitation or thunderstorms.

The Danish Meteorological Institute (DMI) has five radars in Denmark. The radars are located on the earth's surface and within a range of 120 km of each radar, the entire Denmark's atmosphere is covered up to a height of 1 km. The radars are located in Sindal, Virring, on Stevns, Rømø and Bornholm and can be seen in Figure 4.2.

Parts of the planned area for Hesselø OWF are located just within ranges of the meteorological radars on Stevns and in Virring, as the distances between the planned area and the radars on Stevns and in Virring are approx. 117 km and 111 km, respectively (Figure 4.2).

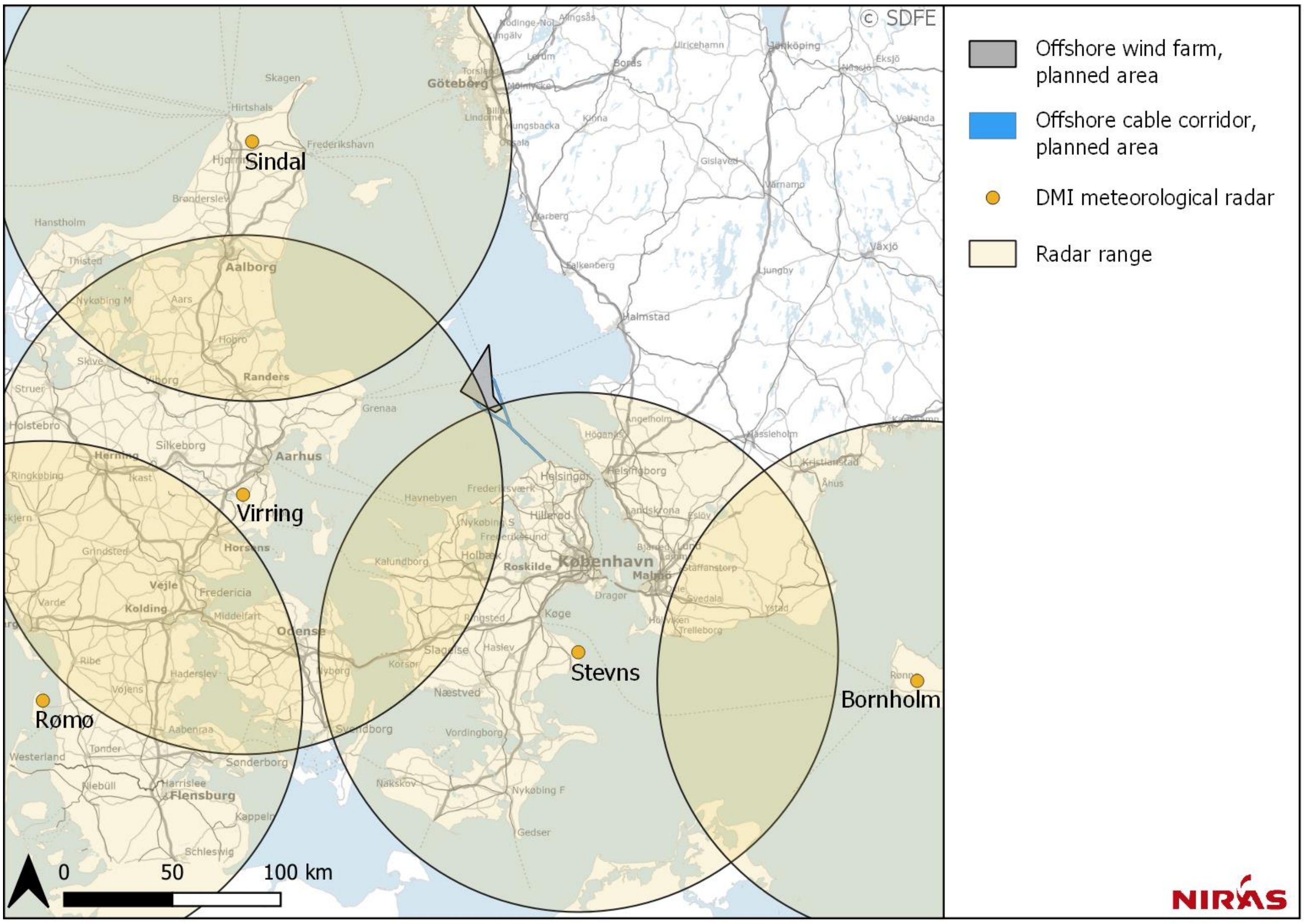

Figure 4.2: Illustrative figure displaying the meteorological radars in Denmark and their ranges in relation to the planned placement of Hesselø OWF.

4.2 Radio chains

A radio chain is a data connection between two positions. Radio chains are used for telecommunications and data transmission of e.g. radio and TV signals in the same way as cable network. It is a good alternative to e.g. cables, especially where cabling is difficult due to the course of the landscape, urban settlements or across water. Radio chains are typically used by mobile operators or by companies that offer broadband for data transmission.

A radio link operates two antennas and in order for the radio chain to function optimally, it is required that there is direct line of sight (LOS) between two antennas. Potential effects on radio chains from offshore wind farms thus include blocking or reflection of radio signals caused by the turbines. It is recommended that there is a minimum of 200 m from an offshore wind turbine or other obstacles to the LOS for a radio chain link, in order to avoid interference with the signal.

An extract from the Danish Energy Agency's frequency register (Frekvensregisteret) for radio chains in the project area for Hesselø OWF shows that there are no “point to point” radio chain in the vicinity of Hesselø OWF. The nearest radio chain is a link between the island of Anholt and Jutland at a position near the city Grenå.

5 Assessment of potential effects

5.1 General effects on radar and radio chains

The extent of potential effects of offshore wind farms on radar systems and radio chains depends on the layout and size of the wind farm, as well as the number and dimensions of the turbines. For example, the closer the turbines are placed to each other, the more shadows and the larger interference will be created by the turbines, and the more difficult it is for the radars to detect targets (e.g. vessels) between the turbines (Hansen, et al., 2012).

Further, the degree of effect is influenced by the distance between the radar and offshore wind farm, so that the closer an offshore wind farm is to a radar, the more likely the wind farm is to interfere with the radar beams. Potential effects on radars generally occur when the turbines are above the Radar-Horizon.

In general, two types of effects of offshore wind farms on radar systems can occur:

- Formation of radar shadows behind wind turbines, which may cause underlying targets to be either poorly detected or not detected at all.
- Reflection of radar beams in wind turbine structures, which may give rise to false radar targets (false echoes).

For radio chains, offshore wind turbines can interfere with links between antennas by blocking or reflecting signals when placed within the LOS of the antennas.

5.2 Potential effects on radar and radio chains in relation to Hesselø OWF

In this section, potential effects on radar systems, aviation facilities and radio chains are addressed in relation to the construction and operation of Hesselø OWF. Potential effects in relation to decommission is not considered since it is estimated that the type and duration of effects on radar systems, aviation facilities and radio chains will correspond to the effects described and assessed for the construction phase.

Potential effects on radar systems, aviation facilities and radio chains during construction will be due to the presence of large work vessels equipped with towers and cranes, while potential effects during operation will be due to the presence of turbines and the rotation of the turbine blades as well as presence of maintenance vessels.

5.2.1 Air traffic radars

According to a Eurocontrol publication regarding guidelines for assessing wind farms and radars (Eurocontrol, 2014), no assessment is required even if Hesselø OWF is within LOS, because air traffic radars are secondary and the distances between Hesselø OWF and the radars are more than 16 km.

Therefore, there is no indication of any Danish civil air traffic radar, which will be affected by the construction or operation of Hesselø OWF and thus no mitigation needed.

5.2.2 Aviation facilities

There are three larger airports, which may be affected by Hesselø OWF: Aarhus, Halmstad and Ängelholm-Helsingborg airports. These airports are located approx. 65, 57 and 55 km from the planned area of Hesselø OWF. Halmstad and Ängelholm-Helsingborg Airports are situated in Sweden. The position of Hesselø OWF in the middle of Kattegat indicates that there will be no obvious problems for in- and out flight procedures, safeguarded zones and electronic aides for these three airports during construction and operation of the wind farm.

The consultant zone for Aarhus Airport with a 60 km radius ("Høringszoner 60 km radius, for hindringer 100m over terræn") (Erhvervsstyrelsen, 2018) does not overlap with the planned area for Hesselø OWF (Figure 4.1). Neither does the MSA surface with 55 km radius for the Swedish airport, Halmstad, while the MSA surface for Ängelholm-Helsingborg Airport may have a small peripheral overlap with the planned are for Hesselø OWF. However, the potential effects on the three airports should be further assessed when the final layout for Hesselø OWF has been decided.

The small public aerodrome on the island of Anholt situated approx. 22 km north-northwest of Hesselø OWF has no instrument procedures, and the safeguarded surfaces are not in the vicinity of Hesselø OWF and therefore no effects are expected to occur in relation to this aerodrome.

The Danish Civil Aviation and Railway Authority will normally consult relevant airports if necessary and coordinate mitigation if needed.

In the construction phase, pilots are warned of temporary obstacles such as tall cranes and ships which may be a potential hazard for aviation. These warnings are published in a NOTAM (NOtice To AirMen) (Naviair).

Thus, no Danish civil radio navigational aids or other facilities for aviation will be affected by the construction or operation of Hesselø OWF according to the available information shown on the Danish Business Authority's webpage (Erhvervsstyrelsen, 2018).

5.2.3 Ship radars

Mobile radar systems on ships will be affected locally, when the ships are in close proximity to the wind farm. Since the effects on ship radars are local in their distribution, and since most ships will use specific sailing routes around the wind farm (DNV, 2021), the effects on ship radars due to the construction and operation of Hesselø OWF is estimated to be negligible.

If a ship uses primary radar and the ship is placed within LOS (Line Of Sight) of Hesselø OWF, the structures and vessels used during construction of the wind farm may be shown on the radar display and the information could be used to navigate safely around the these. This will also apply for the turbines present during operation of the wind farm. However, the OWF might have a negative effect on the operator's display, leading to complications in navigation decision-making (National Academies, 2022). No mitigation is normally needed for primary ship radars.

5.2.4 Meteorological radars

The planned area for Hesselø OWF is located just within the ranges of two of the five meteorological radars used in Denmark (Figure 4.2), but since the overlap is very peripheral, structures such as vessels and turbines during the construction and operation of Hesselø OWF are not considered to be within the LOS any of the five radars, and therefore no effects on the radars are expected to occur.

5.2.5 Radio chains

No point-to-point radio chain will at present be affected by the construction or operation of Hesselø OWF.

5.3 Summary

To summarize, potential effects on civil air traffic, ship and meteorological radars as well as radio chains has been described in relation to the construction and operation of Hesselø OWF. In general, Hesselø OWF will have no adverse effect on radar systems and radio chains, but the OWF might have a negative effect on ship radars.

The Danish Civil Aviation and Railway Authority may consult airports if necessary and coordinate mitigation if needed in relation to aviation facilities and procedures. The assessments are, however, based on an overall level, taking into account the different scenarios and layouts for the plan for Hesselø OWF, and the type, duration and extent of the effects must be assessed in the environmental impact assessment when the final, specific project for Hesselø OWF has been determined.

6 Cumulative effects

Denmark and Sweden both plan to establish additional offshore wind farms in Kattegat within the next decade, and an existing Danish offshore wind farm (Anholt OWF) is already located here (Figure 6.1). With the potential establishment of additional offshore wind farms, the radar monitoring of Danish maritime territory and airspace may potentially be affected. However, due to assumed mitigation measures (see section 7), cumulative effects on radar and radio chains are expected to be insignificant.

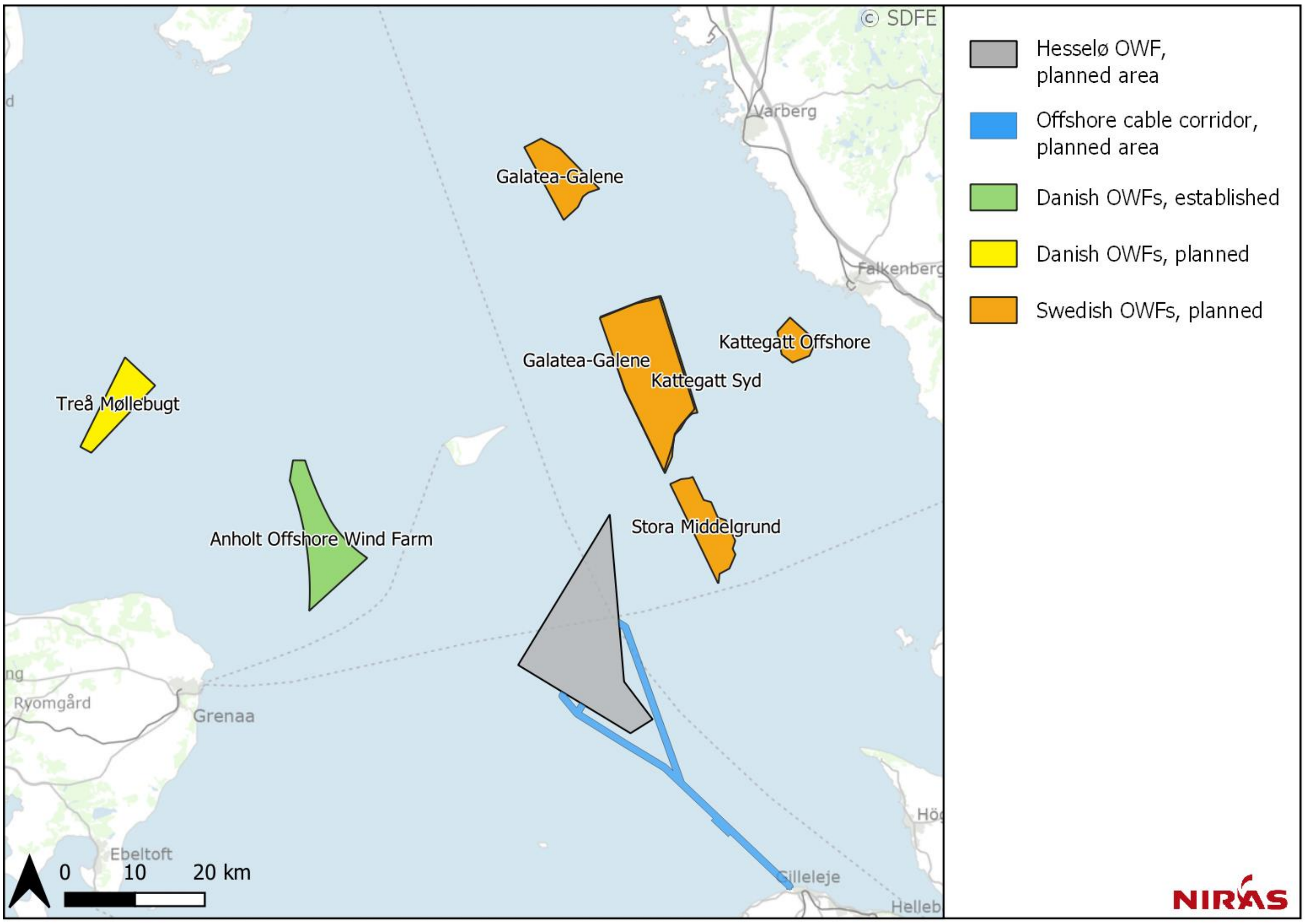

Figure 6.1: Planned and established Danish and Swedish offshore wind farms in Kattegat that may cause cumulative effects on radar and radio chains.

7 Potential mitigation measures

In general, potential mitigation measures for radar systems in relation to establishment of offshore wind farms can include:

- A layout of the offshore wind farm that minimize interference with radar beams and hence radar images, e.g. by adjusting the number, dimensions and distance of and between the turbines.
- Installation of 'gap filling' radars in order to close gaps in coverage caused by the turbines (Terma).
- Upgrade or replacement of radar systems in order to improve monitoring near the turbines.

In relation to air traffic and aviation facilities, modern air traffic control centers and airports may also use advanced software which can combine input from several radars and generate so-called "multi-radar tracks" to be displayed for the air traffic controller (Eurocontrol, 2019). In addition to this, new technology such as Wide Area Multilateration (WAM) may be implemented (Federal Aviation Administration, 2020), which uses multiple sensors instead of classic radars. These technologies may mitigate the loss of radar signals due to shadowing and other unwanted effects.

Other mitigation measures can be found in available literature, such as "Assessing radar mitigation options for wind farm developers" (Pagerpower, 2014). Extensive literature exists for the assessment of radar coverage and the calculation of this. Depending on the type of radar and distance from the radar antenna to the wind turbines, mitigation of effects from wind turbines on radars could vary from a simple assessment to more detailed and complicated assessments (Eurocontrol, 2014).

Based on current knowledge, the construction, operation and decommission of Hesselø Offshore Wind Farm will not require mitigation measures in relation to any civil radar systems and radio chains, since these will not be affected by the establishment of Hesselø OWF (see section 5). However, the conclusions in this report are made on an overall level based on the different scenarios and layouts for the plan for Hesselø OWF, and the extent and type of potential mitigation measures must be considered in greater detail when the final, specific project for Hesselø OWF has been determined.

Finally, potential mitigation measures in relation to military radar systems is not included here, since data has not been provided by the Danish Defence. In the case that establishment of Hesselø OWF may potentially impact Danish military radar systems, it is assumed that the Danish Defence will require appropriate mitigation measures.

8 Monitoring

Monitoring is not considered relevant in relation to radar systems and radio chains.

9 Data and knowledge gaps

As previously stated, this report is based on information on the plan for Hesselø Offshore Wind Farm, and further information and data in relation to radar and radio chains will be available for the environmental impact assessment, when the final project for Hesselø OWF has been determined.

Potential effects relating to military radar systems is not part of this study.

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