ENERGINET – MARINE ENVIRONMENTAL STUDIES

RADAR (CIVIL) AND RADIO INTERFERENCE – KATTEGAT

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Objective:

The objective of the project is to describe and map current civil radars and radio links and provide an assessment of the potential conflicts with having offshore wind farms in the area of Kattegat in Kattegat (Danish sector) and how these can be mitigated.

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1 EXECUTIVE SUMMARY

The purpose of this report is to provide foundational input for a future environmental impact assessment of the potential Kattegat Offshore Wind Farm (OWF). The site is located 15 km east of Djursland (in Jutland, Denmark) and consists of an area which covers 123 km^2. The purpose of this report is to map and present an overview of the current civil radars and radio links in the area, as well as the potential impact on these when establishing, operating, and decommissioning the OWF.

When discussing the impact of offshore wind turbines on radars, aviation facilities, and radio chains, radar interference and radio communication disruption are some of the main subjects. The primary concerns are the shadow effects and reflections caused by these large structures. The effect of wind turbines on radar facilities is primarily influenced by the wind farm's overall size and the number and height of turbines. To tackle these challenges, a range of mitigation measures can be implemented.

The site is within the consultation zone of one Danish airport and an effect on the radars at this airport is therefore possible. The closest German airport is further than 215 km away and the closest Swedish airport is 87 km away. With a distance further than 55 km (minimum horizontal zone) from the Swedish airports, the distance it is assessed that the airports and radars will not be affected during the construction, operation, and decommissioning of Kattegat OWF.

For vessel traffic, the initial comments during HAZID (Hazard Identification Study) workshops raised concerns regarding safety and navigation. Measures like visual markings, turbine locations, inclusion on Navigation Maps and additional coastal radars can mitigate these concerns and possible impacts.

The potential offshore wind farm is within the 240 km range of four Danish meteorological radars and two Swedish meteorological radars. This can impact the radars such as blockage or disturbance. Further assessments are necessary and a dialogue with the Danish Meteorological Institute (DMI) and Swedish Meteorological and Hydrological Institute (SMHI) is recommended.

Regarding radio communications, the planned area for the Kattegat OWF do not have any registered point-to-point radio link permissions. It will be necessary to further assess multipoint-to-multipoint radio chains. This should be done by the future developer by contacting the relevant stakeholders.

Cumulative impacts are possible. There is one established Danish offshore wind farm in the area near Kattegat and one planned. Furthermore, two Swedish offshore wind farms are planned to be established 40-60 km northeast of Kattegat OWF-. It is necessary to assess possible cumulative impacts. With measures to mitigate effects, such as markings, layout, and design of sites, impacts can be reduced.

The results of this report are based on the initial plan for the offshore wind farm, which presents four scenarios using different turbine sizes, numbers, and layouts. The specific impacts, including their types, duration, and overall scale on radar systems and radio links resulting from the Kattegat OWF's construction, operation, and eventual decommissioning, will be conclusively assessed in the forthcoming environmental impact assessment after the project specifics are set.

1.1 Resumé (DK)

Formålet med denne rapport er at give grundlæggende input til en fremtidig miljøvurdering af det potentielle havvindmølleprojekt “Kattegat” i Kattegat. Stedet er beliggende 15 km øst for Djursland og omfatter et område på 123 km². Rapportens formål er at kortlægge og præsentere et overordnet billede af de nuværende civile radarer og radiokæder i området, samt den potentielle påvirkning af disse ved etablering, drift og afvikling af havvindmølleprojektet.

Når man diskuterer påvirkningen af havvindmøller på radarer, luftfartsanlæg og radiokæder, er radarforstyrrelser og forstyrrelser i radiokommunikation nogle af de vigtigste emner. De primære bekymringer er skyggeeffekter og refleksioner forårsaget af vindmøller. Effekten af vindmøller på radar påvirkes primært af vindmølleparkens samlede

størrelse samt antallet og højden af møllerne. For at tackle disse udfordringer kan en række afværgende foranstaltninger implementeres.

Havvindmølleparken ligger inden for høringszonen for én dansk lufthavn, og der er derfor mulighed for en påvirkning på radar ved denne lufthavn. Den nærmeste tyske lufthavn ligger med en afstand på mere end 215 km, og den nærmeste svenske lufthavn er 87 km væk. På disse afstande vurderes det, at de svenske og tyske lufthavne og radar ikke vil blive påvirket under opførelsen, driften og afvikling af Kattegat havvindmøllepark.

Med hensyn til skibstrafik viser de indledende kommentarer under HAZID-workshops til anmærkninger vedrørende sikkerhed og navigation. Foranstaltninger som visuelle markeringer, placering af møller, mærkning på navigationskort og supplerende kystnære radarer kan reducere mulige påvirkninger.

Den potentielle havvindmøllepark ligger inden for en 240 km rækkevidde af fire danske meteorologiske radarer og to svenske meteorologiske radarer. Dette kan påvirke radarerne som blokering eller forstyrrelse. Yderligere vurderinger er nødvendige, og en dialog med Danmarks Meteorologiske Institut (DMI) og Sveriges Meteorologiska och Hydrologiska Institut (SMHI) anbefales.

Med hensyn til radiokommunikation har det planlagte område for Kattegat Havvindmøllepark ingen registrerede tilladelser til punkt-til-punkt radiolinks. Det vil være nødvendigt at vurdere multipoint-to-multipoint radiokæder yderligere. Dette bør gøres af den fremtidige udvikler ved at kontakte relevante interessenter.

Kumulative påvirkninger kan opstå. I området nær Kattegat Havvindmøllepark er der danske og svenske havvindmølleparker, som enten er etableret eller planlagt.. Den nærmeste planlagte danske havvindmøllepark (Hesselø) er 12 km væk. To svenske havvindmølleparker findes i en afstand af 40-60 kmfra Kattegat havvindmøllepark. Mulig kumulative påvirkninger må undersøges. Med foranstaltninger til at afværge effekter, såsom markeringer, layout og design af havvindmølleparken, kan mulige påvirkninger reduceres.

Resultatet af denne rapport er baseret på den indledende plan for havvindmølleparken, som præsenterer fire scenarier med forskellige møllestørrelser, antal og layouts. De specifikke påvirkninger, herunder deres typer, varighed og samlede niveau på radarsystemer og radiolinks som følge af opførelsen, driften og den eventuelle afvikling af Kattegat Havvindmøllepark, vil blive endeligt vurderet i den kommende miljøvurdering, efter projektets specifikationer er fastsat.

2 INTRODUCTION

To achieve the political objective of expanding offshore wind energy in Denmark by the end of 2030, the ”Climate Agreement June 2022” has mandated the commencement of feasibility and preliminary investigative studies for all promising offshore wind zones identified in the 2022 screening. In light of this, the Department of Climate, Energy, and Supply has directed Energinet to conduct marine environmental assessments for the proposed areas for buildout of offshore wind farms (North Sea I, Kattegat, Hesselø, Kriegers Flak II (North and South).

This baseline report has been prepared by DNV on behalf of Energinet in connection with preliminary investigations for the establishment of Kattegat. The purpose of this civil radar and radio interference study report is to map and present an overview of the current civil radars and radio links in the area, as well as the potential impact on these when establishing wind farm in the area Kattegat. The findings from this study will be supplied to the bidders for the offshore wind farm (OWF) project and will serve as critical information for the environmental impact assessment of the particular project.

Kattegat is expected to be operational by the end of 2030 and will have an installed capacity of minimum 1 GW. Final contract with potential developers is expected to be in place in June 2025 (Energistyrelsen, Kattegat Havvindmøllepark).

Due to the proximity of German and Swedish exclusive economic zones (EEZ), mapping of German and Swedish radars has also been carried out.

This report only concerns civil installations. Mapping of military radarsystems is being carried out in a separate study, which also includes coastal radars.

3 PROJECT DESCRIPTION AND SCENARIOS

The Kattegat OWF consists of an area covering 123 km² (Figure 3-1). A cable corridor is planned with landfall south of Grenå, as shown in Figure 3-1.

The OWF is 15 km from the nearest coast, which is the tip of Djursland, Grenå coastal area. The Swedish EEZ border is approximately 42 km east of the planned OWF area.

As part of the environmental assessment, a number of different design scenarios have been agreed with the Danish Energy Agency (DEA) and Energinet. These includes two wind turbine generator (WTG) sizes: 15 MW (with 67 turbines) and 27 MW (with 38 turbines). A base case scenario with a total capacity of 1 GW and an overplanting scenario with total capacity of 2,460 MW is also presented. Each scenario distributes the number of WTGs evenly on the site (Table 3-2).

The boundary of the site is decided and shown in Figure 3-1. Technical parameters have been taken into account, and various scenarios have been formulated, which will influence the results of this study. This report is based on wind farm layout scenarios which are described in Table 3-3, provided by COWI in 2023 (COWI, 2023).

Figure 3-1 Map showing the site for buildout of OWF – Kattegat- and the export cable corridor making a landfall on the eastern coast of Djursland near Grenå. Source: Energinet, 2023

The exemplified site layout for Kattegat will consider four scenarios shown in Figure 3-2.

Table 3-1 Technical specifications of the wind turbine generators (WTGs). Please see Table 3-3 for description of the four scenarios. MSL: Mean Sea Level Source: Cowi, 2023.

	15MW	27MW
Hub Height (m)	146.5	180
Rotor Diameter (m)	233	300
Tip Height (m)	263	330
MSL to lower wing tip (m)	30	30

Table 3-2 Kattegat layout scenarios. WTG: wind turbine generators. Source: Cowi, 2023.

	Wind farm capacity (GW)	WTG capacity (MW)	No of WTG
Scenario-01	1	15	67
Scenario-02	1	27	38
Scenario-03	2.46	15	164
Scenario-04	2.46	27	92

Table 3-3 Description of the four scenarios. WTG: wind turbine generator. HH: Hub Height Source: **(COWI, 2023)**.

Scenario	Description of Table 3-1
Scenario 01	15 MW WTG size, HH 146,5m, rotor diameter of 233m. Maximum tip height will be 263m, ground clearance 30 m relative to sea level.
Scenario 02	27MW WTG size, HH 180m, rotor diameter of 300m, maximum tip height 330m, ground clearance 30 m relative to sea level.
Scenario 03	a base case scenario with a total capacity of 1 GW
Scenario 04	an overplanting scenario with a total capacity of 2,460MW.

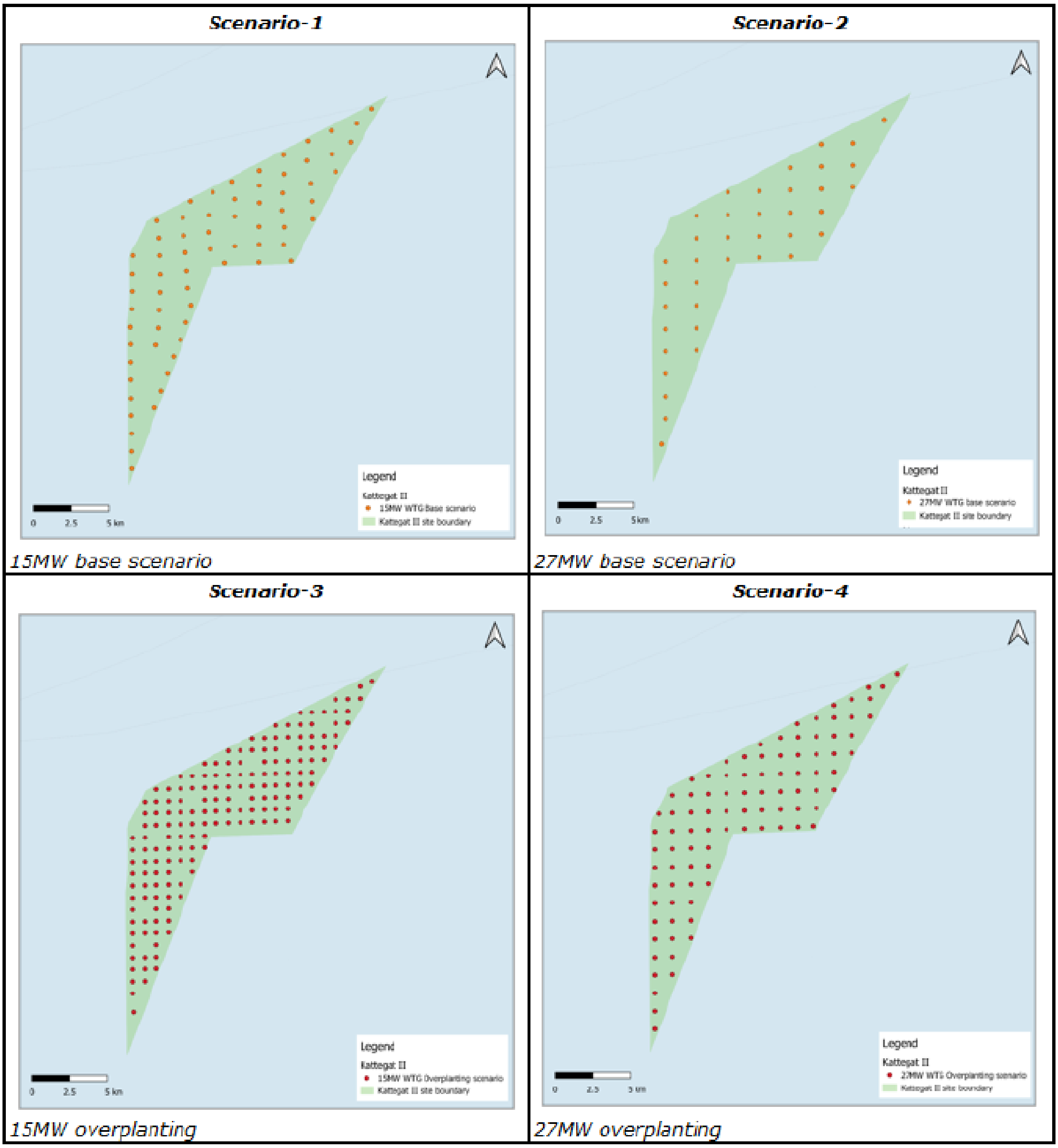

Figure 3-2 Four scenarios derived from layout report. Overplanting scenario: installing more wind turbines than necessary to meet the demand. Base scenario: Installing wind turbines based on average demand and expected wind conditions. Source: **(COWI, 2023)**.

4 METHODOLOGY AND DATA

Offshore wind turbines can impact radar and radio communications in several ways. Radars are used in relation to air traffic and aviation facilities, radio communication and radio chains (frequencies), meteorological radars and maritime traffic, both on vessels and along the coast.

4.1 Method

This is a desktop study, mapping radar installations and radio chains in the area near the Kattegat site. The data has been collected from the following three countries adjacent to the project area: Denmark, Sweden, and Germany.

The data collection consisted of targeting potentially affected installations including air traffic radars and facilities, ship radars, radio chains (frequencies), and meteorological radars.

Coastal radars are placed around the Danish coast but is not part of the civil radar system. The location of these will be mapped but not assessed in this study.

4.2 Data

Danish data of radar installations and radio chains in the area surrounding the Kattegat site have been obtained from the following:

- Danish Civil Aviation and Railway Authority (DCARA) *(Trafikstyrelsen)*
- Danish Energy Agency (DEA)
- Frekvensregistret / Agency for Data Supply and Infrastructure (SDFI)
- Danish Meteorological Institute (DMI)
- Publications

Data from German radar installations has been obtained from the following:

- DWD.de – Deutscher Wetterdienst
- Bundesaufsichtsamt für Flugsicherung
- DFS Deutsche Flugsicherung
- Federal Supervisory Authority for Air Traffic Control (BAF).
- Publications

Data from Swedish radar installations has been obtained from the following:

- Swedish Meteorological and Hydrological Institute (SMHI)
- Transportstyrelsen.se
- Länsstyrelsen.se
- AROWeb
- Trafikverket
- Publications

The planned area – Kattegat - has been provided by Energinet.

The evaluation of cumulative impacts involves areas identified by developers and 4C Offshore. The selection of relevant areas has been conducted in consultation with Energinet.

The assessment is based on four scenarios provided in the background report “Mere Havvind 2030 – Kattegat II & Kriegers Flak II” (COWI, 2023). The four scenarios are described in chapter 3 in present report. The present assessments have been conducted at a general high level, considering various scenarios based on the total installed capacity, turbine sizes, and the resulting variations in the number of turbines and layouts for Kattegat.

5 EXISTING CONDITIONS

In Denmark the regulation regarding radar and radio is set in several regulations and framework. “Safety at sea” (LBK nr. 221 af 11/02/2022) states that certain ships need to be fitted with equipment for navigation, identification, and anti-collision functionalities. Radio chains and radio frequencies falls under the “Frequency regulation” (LBK nr. 151 af 27/01/2021), which sets rules for the use of radio frequencies without permission in ships, aircraft, and ground-based air radio services. Frequency plan (2022) (Energistyrelsen, 2022) and strategy (Energistyrelsen, 2021) describes the current possible use and planned future use of the entire frequency spectrum in Denmark.

The Danish Civil Aviation and Railway Authority (DCAR) (*Trafikstyrelsen*) is responsible for supervision of over 100 airports in Denmark (as well as Greenland and Faroe Islands). These include several different types of airports such as: private, public, heliport, VMC- (Visual Meteorological Conditions) and IMC (Instrument Meteorological Conditions) airports (Trafikstyrelsen, 2023).

Across the nation, and particularly in proximity to airports, various installations are in place, serving both aircraft and air traffic control. These can potentially be impacted by installations such as wind turbines or cranes (during installation of wind turbines).

5.1 Radars

The term “radar” stands for Radio Detection And Ranging, and functions by sending out a burst of radio waves. When these waves encounter an object, they are reflected, and the radar system measures how long the waves take to return. This measurement is used to ascertain the distance of the object from the radar. By using rotating radars, observation can be extended in various directions. The use of radar is diverse, encompassing airspace surveillance, ship traffic monitoring, military targeting, weather forecasting, and measurement activities (CanWEA, RABC, 2020).

The principle of radars is a radar antenna that transmits a radar signal, which is a signal with short impulse and high frequency (1-40 GHz), in one direction. When the signal is reflected on airplanes or ships, a small amount of the signal returned to the radar as an echo. The echo is used to determine the distance and direction of the target which has been detected. The direction is identified by the orientation of the antenna, the distance is defined from the time the reflection uses to return to the antenna. The radar operates independent of time and weather conditions. For how long distance the radar can operate depend on several factors such as, the size of the antenna, the antenna’s location above the ground surface, wavelength, pulse length, received noise, the intensity of the echo. Radar also detects reflections from solid objects which are not moving. This phenomenon is named as noise or clutter (NIRAS, 2022; CanWEA, RABC, 2020).

5.1.1 Civilian Air traffic radars and facilities

Civil aviation surveillance radars are being used for monitoring air traffic in Denmark. A range of facilities are in place for use by aircraft and flight control. These facilities encompass communication systems, navigation aids, and surveillance equipment (radar), collectively known as CNS installations, where CNS stands for Communications, Navigation, and Surveillance. NAVIAR operates the majority of air traffic service facilities (Trafikstyrelsen, 2023).

Danish airports utilize two radar systems for tracking air traffic: primary and secondary radars. These two systems are often used in tandem to provide a complete picture of the airspace, with primary radar offering wide-area surveillance and secondary radar providing detailed identification and altitude information (NIRAS, 2022).

Primary radars emit microwave pulses to detect any object in their vicinity, such as aircraft, and reflects it back to the radar system. It detects the range and bearing of objects but cannot determine the altitude unless it’s a 3D radar.

Secondary radars rely on a transponder in the aircraft. The radar sends a coded signal to the aircraft, and the transponder responds with a return signal containing specific information like the aircraft's identity, altitude, and sometimes speed. It is used for a more comprehensive picture by identifying the individual aircraft and additional data.

The effectiveness of both primary and secondary radars is not just a function of their technical design, but also critically depends on the clear line of sight to the targets they are tracking. The coverage of both primary and secondary radars is heavily influenced by the system's design and, most crucially, the existence of a direct line of sight (LOS) between the radar antenna and the target, such as an aircraft or ship. For a radar system to detect and track an object effectively, there must be an unobstructed path between the radar antenna and the object; a direct line of sight. If there are obstructions like mountains, buildings, or in the case of offshore structures, large wind turbines, the radar signal may not reach the target, leading to detection issues.

It is possible to calculate if obstructions (like wind turbines) will obstruct the radar coverage. The radar coverage formula takes into account the height of the radar antenna and the height of the object.

The Minimum Sector Altitude (MSA) in aviation, as defined by the International Civil Aviation Organization (ICAO), is the lowest altitude which may be used to provide a minimum clearance (MSA) of 300 meters (1,000 feet) above all objects within a sector. Obstacle Limitation Surfaces (OLS) are a series of defined surfaces that extend outwards and upwards from an airport, designed to safeguard the airspace around the airport for safe aircraft operations. They ensure that buildings, structures, or natural features do not pose a hazard to aircraft taking off, landing, or flying in the vicinity of the airport (ICAO, 2009). In Denmark a consultancy zone is specified with 60 km. In this zone it is necessary to assess any planned constructions that might impact the airport within this zone. In Denmark, some aviation facilities are completely or partially protected with easements in a radius of 300 meters. Danish Aviation facilities also have safety zones to wind turbines of 15 km (Figure 5-1) (Trafikstyrelsen, 2023).

In Sweden, a MSA is specified with 55 km horizontal zone. MSA areas with 55 km zone are only present at airports with instrument flight procedures according to Trafikverket (2014). Sweden has 50 airports with instrument flight procedures that have MSA areas (Figure 5-1) (Trafikverket, 2014).

In Germany, air traffic and aviation facilities use VORs (very high frequency omnidirectional radio range) and DVORs (Doppler very high frequency omnidirectional radio range). The protected areas around 40 ground-based navigation facilities are 7 km. Several VORs will be decommissioned by 2032 and some VORs will be replaced by DVORs. Flugplatz Güttin near Rügen is the nearest airport in Germany to Kattegat. This is planned to be decommissioned (Figure 5-1) (DFS, N/A).

5.1.1.1 Danish Aviation Facilities

Kattegat OWF is situated outside the 15 km wind farm exclusion zone for proximity to airports (Figure 5-1). Kattegat OWF is, however, within the 60 km consultancy zone of Aarhus Airport.

There are other smaller aviation facilities close to the project area, which have smaller Obstacle Limitation Surfaces and does not have a consultancy zone. These are Anholt Flyveplads (28 km north-east), Trano Airfield (53 km south), Kalundborg Airport (58 km south), and Sams Airport (50 km south-west) (Figure 5-1).

5.1.1.2 Adjacent countries

The two closest airports in Sweden, which has a MSA zone, are about 87 km away. These are Halmstad and Ängelholm-Helsingborg Airport and are not within the MSA zone (Transportstyrelsen) (Figure 5-1).

At the present time the closest airport in Germany near Kiel is 215 km away (Figure 5-1) (Bundesaufsichtsamt für Flugsicherung, 2023; DFS, N/A).

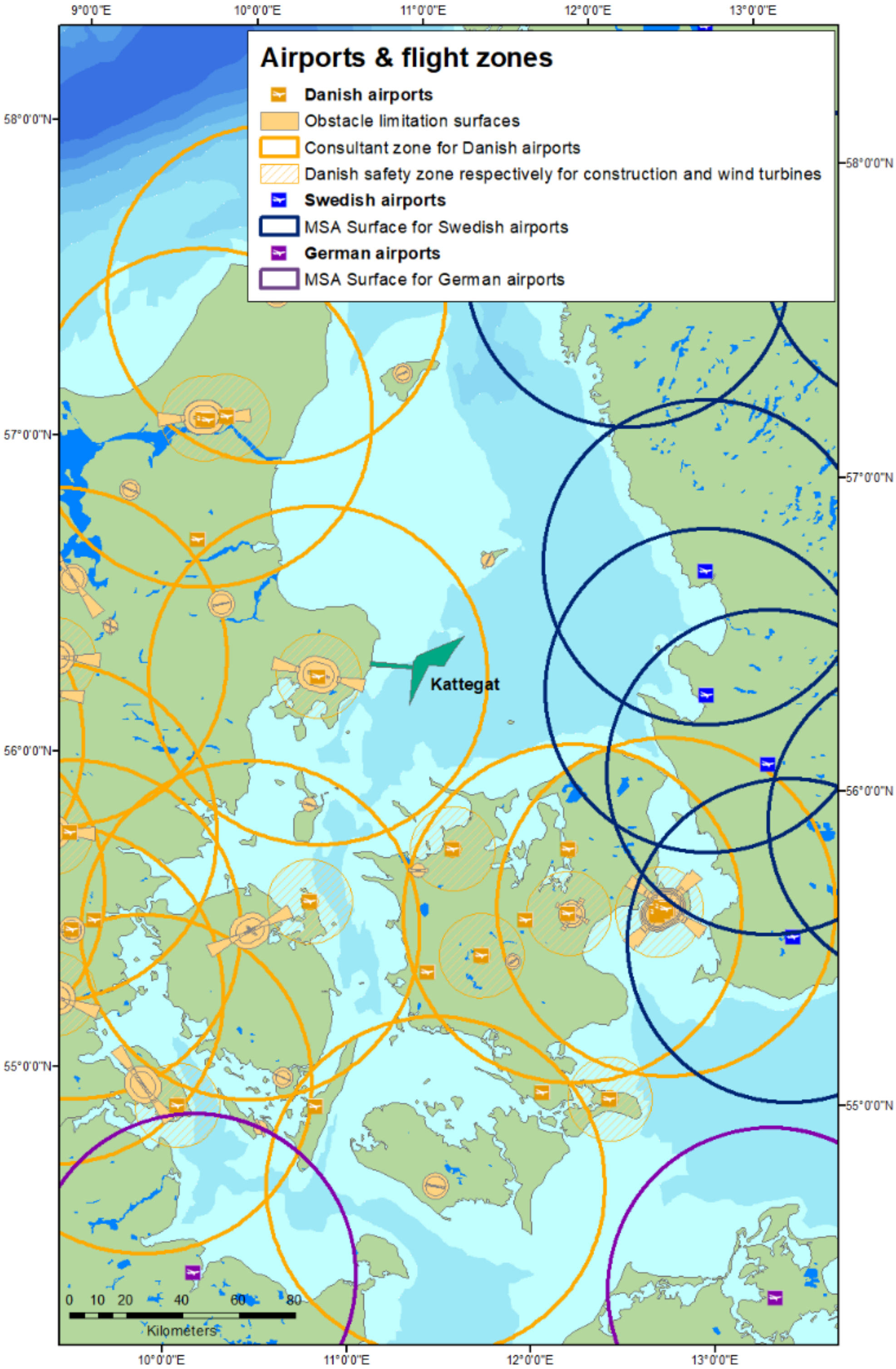

Figure 5-1 Airports and flight zones for Danish, Swedish and German airports. Sources: Energinet, 2023; Plandata.dk, 2023

5.1.2 Vessels radars

The use of mobile radar systems in both commercial and non-commercial marine vessels play a vital role in enhancing navigational safety and efficiency. One of the primary functions of radar on ships is to detect other vessels and obstacles. This allows for timely manoeuvres to avoid collisions, a critical aspect in busy shipping lanes or crowded marinas. Radar systems also help in identifying landmasses, coastlines, and navigational markers, especially in poor visibility conditions like fog or darkness. This is crucial for safe navigation, particularly in unfamiliar or congested waters.

There is active ship traffic in the area based on AIS data from 2022 (Figure 5-2). Kattegat is placed outside most of the main routes. However, ships with a larger draft stay in the greater depth, which is through the area designated for the Kattegat Havvindmøllepark. (DNV, 2024).

Wind turbines can result in potential impact with blocking or reflecting radar signals (see ch. 6.1). Two HAZID workshops have been performed concurrently with this radar study. The impact from wind turbines on vessel radar regarding interference between vessel and coastal radars was mentioned in the HAZID. With mitigative actions the impacts can be reduced (see ch, 8 regarding mitigative measures). For mapping of coastal radars (see 5.1.2.1).

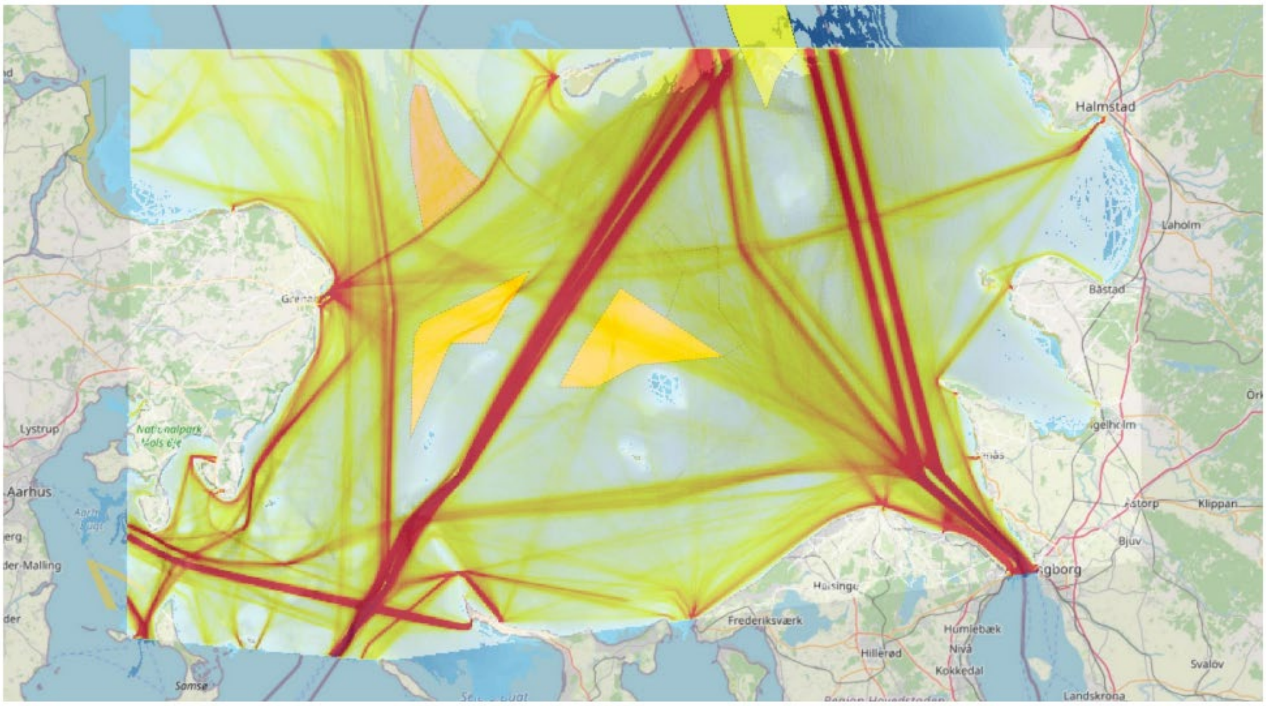

Figure 5-2 Vessel routes based on AIS data from 2022. The offshore wind farm areas Kattegat and Hesselø are shown as orange. Kattegat is located west and Hesselø east. Source: HAZID Report Kattegat **(DNV, 2024)**

5.1.2.1 Coastal radars

In relation to vessel traffic, coastal radar stations are located along the Danish coast (Figure 5-3 and Figure 5-4). The network is known as Kystradar (KYRA) and Vessel Traffic Services (VTS). These are established by Danish Defence. The stations are instrumental in observing and managing coastal shipping movements. These are used for ocean monitoring in relation to execution and control of search and rescue operations, control of ships that transport dangerous or polluting goods, combating terrorist activities, etc. Data collected by the radar sensors at each station is relayed to central control rooms, where the Danish Defence supervises maritime activities and other relevant operations. Additionally, some of these stations are enhanced with specialized radar systems for tracking activities in the lower airspace. (Balsved, 2007)

The potential impact and assessment on coastal radars by Kattegat OWF will not be covered in this study, but in a separate study on none-civilian radars.

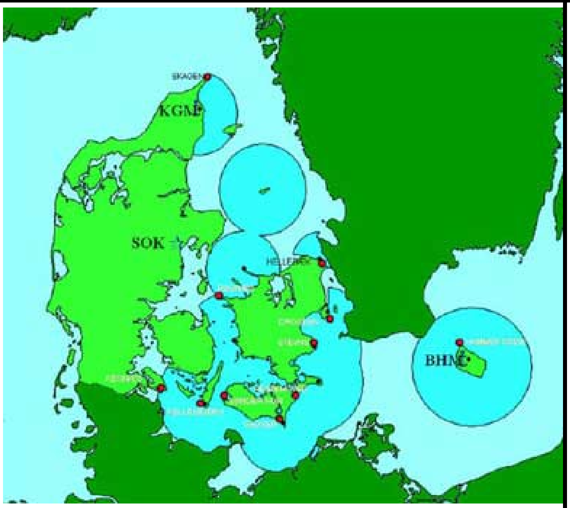

Figure 5-3 Radar Stations before KYRA project in 2000-2004. Sources: Danish Naval History (kystradarprojektet (KYRA)), 2007.

Figure 5-4 Additional radar stations after KYRA project in 2004. Sources: Danish Naval History (kystradarprojektet (KYRA)), 2007.

5.1.3 Meteorological radars

Five radars have been set up by the Danish Meteorological Institute (DMI) for precipitation detection throughout Denmark. Positioned on the ground, these radars have the capability to scan the atmosphere/precipitation to a range of 240 km and several kilometres vertically. The five radars in Denmark are located at Stevns, Sindal, Virring, Rømø, and Bornholm.

In 2017 three of the meteorological radars at Stevns, Rømø and Sindal were upgraded and a few years before this, two new radars at Bornholm and Virring were installed. Each of these five radars were then a “dual-polarization C-band” with Doppler capability, which enables the measurement and classification of the volume of precipitation particles. This enhances the accuracy in differentiating types of precipitation, such as rain, snow, or sleet. Additionally, it allows for the assessment of precipitation particle size and the measurement of wind speed and direction during precipitation events (DMI).

The Kattegat site is situated within the operational scope of 4 of the 5 meteorological radars in Denmark: Sindal, Rømø, Virring and Stevns (Figure 5-5).

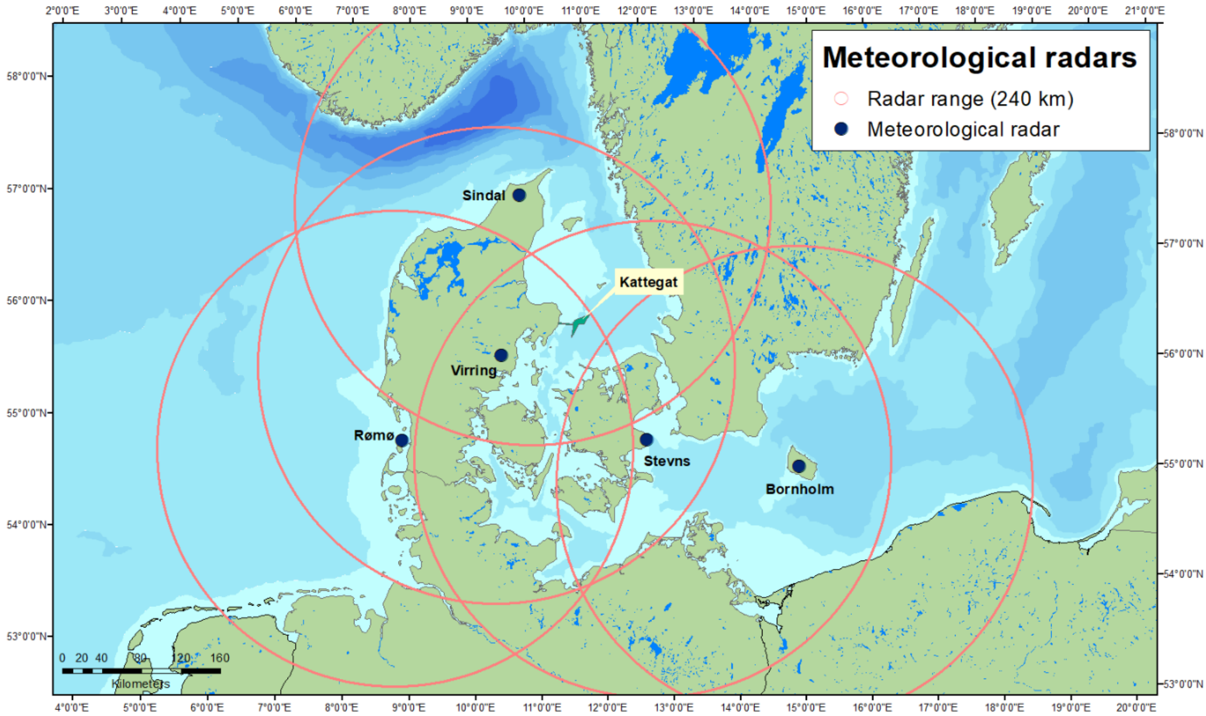

Figure 5-5 The five meteorological radars in Denmark and Kattegat offshore wind farm (OWF) area, showing a range of 240 km. Source: DMI, 2023; Energinet, 2023

Table 5-1 Location and metadata concerning Danish Meteorological Institutes (DMI) radar stations. Source: **(Atlassian, 2023)**.

Name	StationID	Owner	Latitude	Longitude	Active from
Rømø/Juvre	60960	DMI	55.1725903	8.55052996	01-03-1992
Sindal	06036	DMI	57.48876226	10.13511376	01-07-1994
Bornholm	06194	DMI	55.11283297	14.8874575	05-03-2002
Stevns	06177	DMI	55.32561875	12.44817293	01-04-2001
Virring Skanderborg	06103	DMI	56.02386909	10.02516884	01-11-2008

In Sweden the meteorological radar network consists of 12 C-band Doppler weather radars (Norin, 2017). The maximum range for Swedish weather radar installations is 240 km. At this distance, and with an elevation angle of 0.5°, which is the lowest for Swedish installations, the height of the radar beam above the ground is around 5-6 km. This is in contrast to the antenna's placement, which is about a dozen meters above the ground (SMHI, 2023). The two nearest meteorological radars are near Ängelholm, which is about 87 km away, and Vara 220 km away (Figure 5-6). (Norin, Researhgate, u.d.)

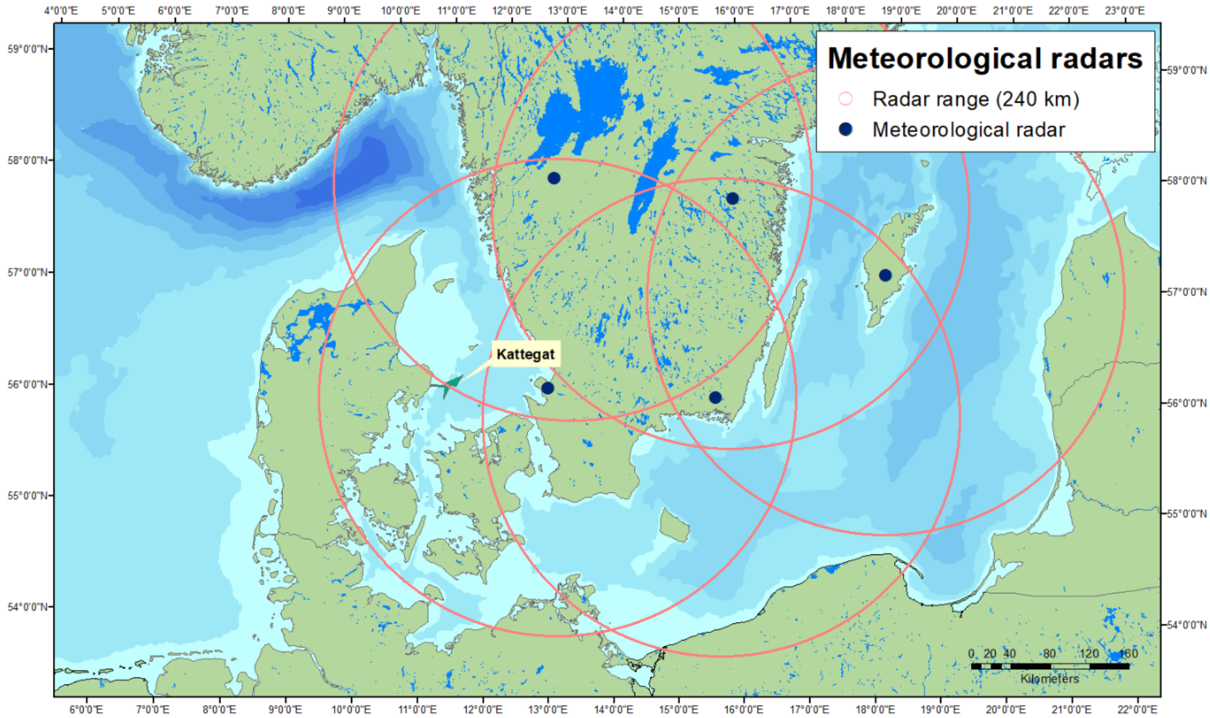

Figure 5-6 The relevant meteorological radars in Sweden, showing a range of 240 km. Sources: SHMI, 2023; Researchgate,N/A; Energinet, 2023

Table 5-2 Location and metadata concerning Swedish SHMI radar stations. Sources: SMHI, 2023; Norin, Researhgate, u.d..

Name	Latitude	Longitude
Kiruna	68.7088	20.6178
Luleå	65.4309	21.8650
Örnsköldsvik	63.6395	18.4019
Hudiskvall	61.5771	16.7144
Leksand	60.7230	14.8776
Arlanda	59.6544	17.9463
Vara	58.2556	12.8260

Vilebo	58.1059	15.9363
Ase	57.3035	18.4001
Ängelholm	56.3675	12.8517
Karlskona	56.2955	15.6103

In Germany there are 17 meteorological radars. The German Weather Service (DWD) receives detailed radar scans every five minutes, offering real-time precipitation echo data. Initially, the Precipitation Scan measures nearby rainfall up to 150 km away. Following this, ten different angles are used to scan the atmosphere up to 180 km, providing insights into the height and spread of precipitation areas. The high-resolution data is instrumental in closely tracking weather patterns and severe weather occurrences (DWD, 2017). There are no radars that reaches the Kattegat site (Figure 5-7).

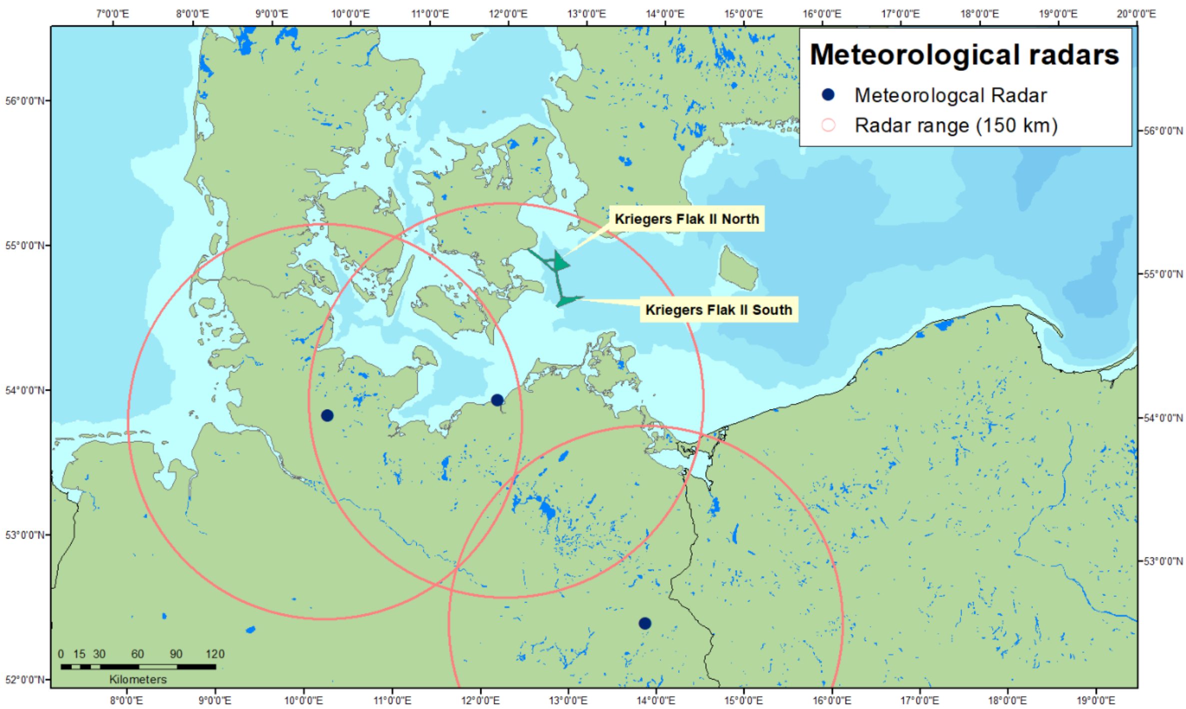

Figure 5-7 The relevant meteorological radars in Germany with a 150 km radius. Source: DWD, 2017; Energinet, 2023

Table 5-5-3 Location and metadata concerning German Weather Service (DWD) radar stations (DWD, 2017)

Name	Geographic coordinates WGS 84 (Latitude/Longitude)
ASR Borkum	53° 33‘ 50,44“N 6° 44’ 53,85“E
Boostedt	54° 00' 15,8"N 10° 02' 48,8"E
Dresden	8 51° 07' 28,7"N 13° 46' 07,1"E
Eisberg	49° 32' 26,4"N 12° 24' 10,0"E

Essen	51° 24' 20,3"N 06° 58' 01,6"E
Feldberg	47° 52' 25"N 08° 00' 13"E
Flechtdorf	51° 18' 40,3"N 08° 48' 07,2"E
Hannover	52° 27' 36,3"N 09° 41' 40,3"E
Isen	48° 10' 28,9"N 12° 06' 06,4"E
Memmingen	48° 02' 31,7"N 10° 13' 09,2"E
Neuhaus	50° 30' 00,4"N 11° 08' 06,1"E
Neuheilenbach	50° 06' 34,8"N 06° 32' 54,0"E
Offenthal	49° 59' 05,1"N 08° 42' 46,6"E
Prötzel	52° 38' 55,2"N 13° 51' 29,6"E
Rostock	54° 10' 32,4"N 12° 03' 29,1"E
Türkheim	48° 35' 07,4"N 09° 46' 57,6"E
Ummendorf	52° 09' 36,3"N 11° 10' 33,9"E

5.2 Radio chains

A radio chain is a so-called fixed service. A fixed service can also be point-to-multipoint systems like FWA (Fixed Wireless Access) or multipoint-to-multipoint system like MWS (Multimedia Wireless System). Radio chain is typically characterized by there being a line of sight between the transmission and reception stations, and where the positions of both the transmission and reception stations are known.

A point-to-multipoint system, often wireless subscriber networks like FWA, refers to fixed radio connections where the base station's (transmitter station's) location is known, while the receiving station's position is not precisely known (CanWEA, RABC, 2020).

Multipoint-to-multipoint systems involve receivers communicating with multiple base stations.

Point-to-point radio chains are extracted from DCARA (*Trafikstyrelsen*) Frekvensregistret.dk. In the guideline of DBA (Danish Business Authority), a general guideline is to maintain a 200-meter distance from the line of sight, but it's important to note that this is just a rule of thumb. It's advisable to consult with the specific permit holder to check for any potential conflicts. Multipoint-to-multipoint ("flade til flade") radio communication is not shown on this registry, and it will be up to the developer to contact owners of these to map out any existing connections of this sort.

An extraction from Frekvensregistrert.dk shows no "point to point" radio chains in the Kattegat OWF area and vicinity.

6 ASSESSMENT

6.1 Potential impact of radars and radio chains

When discussing the impact of offshore wind turbines on radars, aviation facilities, and radio chains, radar interference and radio communication disruption are some of the main subjects. The primary concerns are the shadow effects and reflections caused by these large structures.

Reflection

The large, moving blades of wind turbines can reflect radar signals, creating “clutter” on the radar screen. This can lead to false signals or the masking of actual aircraft or weather patterns. This can be particularly problematic for air traffic control, as turbines can mimic the movement of aircraft on radar displays or mask the presence of actual aircraft (CanWEA, RABC, 2020).

The rotating blades can also distort the Doppler frequency of the radar signal, affecting systems that rely on Doppler shifts to measure object speed. These radars can interpret turbine blade movement as atmospheric motion, leading to inaccurate readings.

Wind turbines can also interfere with radio communications. This is because their large metal structures can reflect or diffract radio waves, leading to signal loss or degradation. This can affect a wide range of communication systems, including marine VHF, aviation communications, and even terrestrial TV and radio broadcasts.

Shadowing

Radar shadowing is when wind turbines, particularly the larger offshore types, can create areas of “radar shadow”. This occurs when the turbine obstructs the line of sight of a radar, causing a blind spot.

For aviation or maritime radars, this means that aircraft or ships within this shadow zone might not be detected. This can pose significant safety concerns (CanWEA, RABC, 2020).

For meteorological radars these shadow effects can result in inaccurate weather readings. Wind turbines can block the radar’s ability to detect precipitation or storm formations in certain areas, leading to gaps in weather data crucial for forecasting.

Radio chains

Impact on radio chains can occur if line of sight is obstructed. Naturally obstruction can happen when a target aircraft or ship is below the radar horizon (the point where the Earth’s curvature obstructs the LOS), and it will not be detected. Similarly, if there is any hindrance along this path (Line of Sight), it will cause a major decrease in the radio signal, thereby deeming the path ineffective (CanWEA, RABC, 2020).

6.2 Potential impact in relation to Kattegat OWF

The potential impacts on radar installations and radio chains are solely due to the presence of offshore wind turbines. These effects will persist throughout the wind farm’s lifespan, being minimal at the start of construction and increasing as more turbines are installed, reaching maximum when all turbines are in operation. The same impact during decommissioning and construction phase is expected (CanWEA, RABC, 2020; NIRAS, 2015), and the potential impact in this study is therefore assessed in relation to the construction and operation phase of Kattegat OWF.

The effect of wind turbines on radar facilities is primarily influenced by the overall areal size of the wind farm, height of turbines and the number of turbines. The space between the turbines also affects radar signal quality; the closer the turbines are to each other, the higher potential impact from interference and shadowing, which in turn will make it challenging for vessels to use radars (Energinet.dk, NIRAS, 2015).

For Kattegat OWF the tallest wind turbine in the four layout scenarios are 330 meters (38 turbines of 27 MW) and the lowest 263 meters (67 turbines of 15 MW) (Chapter 3). This is a near doubling in the number of the lowest turbines. The two base scenarios (1 and 2) show a similar spacing between the turbines. The two overplanting scenarios (3 and 4) shows different spacing, where the scenario with smaller WTG capacity (15 MW, 230 no. WTG) presents much smaller spacing between turbines, than the larger capacity turbines (27 MW, 128 no. WTG).

6.2.1 Air traffic and aviation facilities

Kattegat OWF is within the consultation zone for Aarhus Airport (60 km) (Plan- og landdistriktsstyrelsen). Dialogue with the Danish airports and the potential effect should be further assessed by the future developer. It is advised to start this dialogue early since the assessment can affect the design of the OWF.
During dialogue between Energinet A/S and Aarhus Airport, it was highlighted by the airport authorities that the project's design should be assessed to impact the approach procedures for Runway 28L at AAR. The developer is anticipated to absorb the costs for modifying the procedure design and conducting any required test flights.

The smaller aviation facilities and airports do not have a consultation zone and will most likely not be impacted by the OWF given their distance and type, but it is however recommended to start an early dialogue with these airports.

There are no Swedish or German airports and their MSA surface that overlaps with the Kattegat OWF (Figure 5-1).

6.2.2 Vessels radars

Wind turbines situated along or close to the line of sight of a vessel radar can affect a Marine Communications and Traffic Services Operator's capability to differentiate between actual and false targets, due to the scattering effects caused by these nearby wind turbine installations. The severity of interference depends upon the angle of the vessel traffic control radar beam to the wind turbine (CanWEA, RABC, 2020).

One HAZID has been performed for Kattegat, simultaneously of this report. In the HAZID-workshop a few concerns were raised regarding safety and navigation (DNV, 2024). Mitigation measures like additional radars along the coast is mentioned in chapter 8. It should be noted that the potential impacts on coastal radars (owned and operated by the Danish Defence) will not be assessed in this study.

The four layout scenarios (COWI, 2023) present a difference in number of turbines and space between the turbines. The closer the turbines the higher the potential interference and shadowing impact. When designing the OWF the layout should therefore be considered to reduce the risk of impact.

The potential impacts should be further assessed by the future developer and discussed with Danish Coast Guard authority.

6.2.3 Meteorological radars

In general, meteorological radars have a range of 240 km in Denmark and adjacent countries. The Kattegat site is within Sindal, Rømø, Virring and Stevns meteorological radar range with the closest radar (Virring) being approximately 72 km away from the southern part of Kattegat site. The Danish meteorological radars use the Doppler effect to detect precipitation, which can be impacted by the tip of the blade and turbulence. Blockage can also impact the radar and loss of data (CanWEA, RABC, 2020; Norin, 2017).

The Kattegat site is within the LOS of four Danish meteorological radar ranges, as well as two Swedish radars, and potential impacts, like blockage and reflection are expected to occur. The potential impact and mitigating measures should be further assessed by the future developer and discussed with the Danish Meteorologist Institute (DMI) and The Swedish Institute (SMHI).

6.2.4 Radio chains

There are currently no point-to-point radio chains in or near the Kattegat area. These will therefore not expect to be impacted by the offshore wind farms.

Regarding multipoint-to-multipoint (“flade til flade”) radio communications; this will be up to the developer to contact owners of these to map out any existing connections of this sort.

7 CUMULATIVE IMPACTS

One offshore wind farm (Anholt) is established in close vicinity to Kattegat OWF and one is planned to be established (Hesselø) (Figure 7-1). Anholt is an existing OWF which is located north of Kattegat OWF, established 2013. The planned Hesselø OWF is being assessed parallel to this study.

Galatea and Galene are Swedish OWF planned to be established as part of Sweden's energy policy goals of renewable energy by 2040 (OX2, 2020).

There are very few existing and planned OWFs near Kattegat OWF. It is necessary to assess possible impact due to cumulative effects by future developer in environmental assessments.

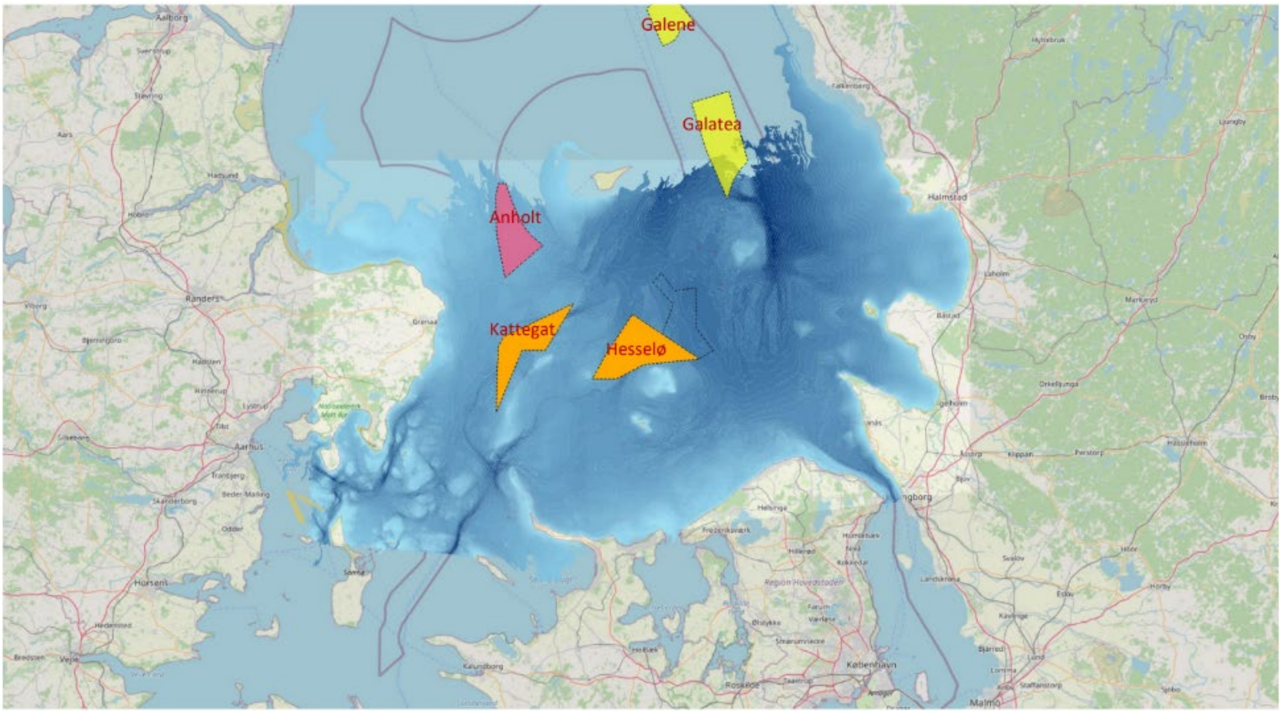

Figure 7-1 Established and planned offshore wind farms (OWF) in the Kattegat. Orange areas: Kattegat OWF and Hesselø OWF (Hesselø is being assessed concurrently with Kattegat OWF), red areas: existing OWF, yellow: OWF planned to be established in Sweden. Source: HAZID report Kattegat **(DNV, 2024)**

8 MITIGATION MEASURES

Offshore wind turbines offer significant benefits for renewable energy, but they can also pose challenges to radar, radio systems, and vessel traffic. To address these issues, various mitigation strategies can be employed.

Radar and Radio Communication Challenges:

- **Radar Interference:** Wind turbines can cause shadow effects and reflections that interfere with radar systems. This is particularly problematic for weather radars and aviation.
- **Radio Communication Disruption:** The turbines can also disrupt radio communication, which is crucial for both maritime and aviation safety.

Mitigation Strategies:

1. **Advanced Radar Systems:** Specialized radar systems with improved filtering capabilities are being developed to reduce wind turbine interference. This includes adjusting the positioning of radars and employing technology that can filter out the noise created by turbines. (CanWEA, RABC, 2020; Norin, 2017; Omar Abu Ella, Khawla A. Alnajjar, 2022).
2. **Wind Farm Layout Optimization:** Altering wind farm layouts to minimize line of sight obstructions can significantly reduce shadow and reflection impacts (CanWEA, RABC, 2020; Norin, 2017; Omar Abu Ella, Khawla A. Alnajjar, 2022).
3. **Turbine Design Innovations:** Turbine designs that minimize radar cross-sections are being explored. This involves using materials that absorb rather than reflect radar signals and implementing stealth technology (CanWEA, RABC, 2020; Norin, 2017; Omar Abu Ella, Khawla A. Alnajjar, 2022).
4. **Digital Signal Processing:** For radio communication, techniques such as using directional antennas, adjusting antenna locations or heights, and digital signal processing to filter out interference are being developed (CanWEA, RABC, 2020; Norin, 2017; Omar Abu Ella, Khawla A. Alnajjar, 2022).
5. **Cooperative Efforts:** Collaborative solutions involving wind farm developers, radar operators, and regulatory bodies are crucial. These efforts aim to balance efficient energy generation with uninterrupted radar and radio operations (CanWEA, RABC, 2020; Norin, 2017; Omar Abu Ella, Khawla A. Alnajjar, 2022).
6. **Software Solutions:** Research indicates that installing filters in radar signal processors can mitigate impacts on weather stations. Software filters and masks might reduce clutter effects, but they can also create blind spots or gaps in radar displays, necessitating further investigation (CanWEA, RABC, 2020; Norin, 2017; Omar Abu Ella, Khawla A. Alnajjar, 2022).
7. **Vessel Traffic Safety:** Specific lighting on wind turbines and other measures are being explored to mitigate impacts on vessel traffic, as detailed in navigational safety and risk assessments (CanWEA, RABC, 2020; Norin, 2017).

In conclusion, while offshore wind turbines present significant challenges to radar, aviation, and radio communications, ongoing research and collaborative planning are essential. These efforts aim to mitigate impacts, allowing for the harmonious coexistence of offshore wind farms with essential communication and surveillance systems. The balance of these factors is crucial in ensuring the reliability of communication and detection systems while harnessing the benefits of renewable energy.

9 DATA AND KNOWLEDGE GAPS

This study is based on information retrieved from publications and radar operators' websites. When the specific offshore wind farm to be installed in Kattegat are known and decided, it will be necessary to gather more detailed information and data in relation to radar and radio chains (point-to-point and multipoint-to-multipoint) when the developer for Kattegat OWF is determined and the environmental impact assessment is to be commenced.

Going forward it will be necessary to gather more detailed information and data in relation to cumulative impacts.

A stakeholder study should be prepared. A suggestion of relevant stakeholders (non-exhaustive list) is presented in Table 9-1.

Table 9-1 List of potential stakeholders to consider for an Environmental Impact Assessment.

Country	Type	Stakeholder
Denmark	Aviation	NAVIAR
	Aviation	DCARA (Trafikstyrelsen)
	Meteorological Radar	Danish Meteorological Institute
	Radio Chains	Owners of chains
	Ship Traffic	HAZID
Sweden	Aviation	Transportstyrelsen
	Aviation	AROWeb
	Meteorological Radar	SMHI, Sveriges meteorologiska och hydrologiska institut

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