ENERGINET – MARINE ENVIRONMENTAL STUDIES

RADAR (CIVIL) AND RADIO INTEREFERENCE – Kriegers Flak II North & South

Energinet Eltransmission A/S

Report no.: 2023-4114, Final
Document no.: 2088015
Date: 2023-12-15
Date this version: 2024-06-13

DNV

Project name:	Energinet – Marine environmental studies	DNV Denmark A/S
Report title:	RADAR (CIVIL) AND RADIO INTEREFERENCE – Kriegers Flak II North & South	Tuborg Parkvej 8 2900 Hellerup
Customer:	Energinet Eltransmission A/S, Tonne Kjærsvej 65 7000 Fredericia Denmark	Company reg.no. 89 83 23 14
Customer contact:	Amalie Rasmussen	
Date of issue:	2023-12-15	

Project no.:	10443476
Organisation unit:	Risk Management-1330-DK
Report no.:	2023-4114. Final
Document no.:	2088015

Applicable contract(s) governing the provision of this Report: Doc. No. 22/03837-11 – Service agreement incl. consultancy services regarding marine environmental studies for Danish offshore wind 2030 – LOT2

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 areas of Kriegers Flak II North and South in Kattegat (Danish sector) and how these can be mitigated.

Prepared by:	Verified by:	Approved by:
Marie Brolev Senior Consultant	Brit Fjone Godal Principle Consultant	Kjersti Myhre Senior Principle Consultant

The information in this document is classified as:

☒ Open ☐ DNV Restricted ☐ DNV Confidential* ☐ DNV Secret*

Rev. no.	Date	Reason for issue	Prepared by	Verified by	Approved by
A	2023-12-15	First draft	M.Brolev	B.F. Godal	K.Myhre
B	2024-01-04	Second draft	M.Brolev	B.F.Godal	K.Myhre
C	2024-02-27	Third draft	M.Brolev	B.F.Godal	K.Myhre
Final	2024-06-13	Final version	M.Brolev	B.F. Godal	K.Myhre

Table of contents

1 EXECUTIVE SUMMARY

The purpose of this report is to provide foundational input for a future environmental impact assessment of the potential Kriegers Flak II North and South offshore wind farm sites. The sites are located east of Stevns and Møn and consists of two sites (North and South) which covers an area of 174 km^2 in total. 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 offshore wind farm sites.

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 northern site is within the consultation zone of two Danish airports and one Swedish airport, and an effect on the radars at these airports is therefore possible. The closest German airport is further than 60 km away (minimum horizontal zone) and at this distance it is assessed that the airports and radars will not be affected during the construction, operation, and decommissioning of Kriegers Flak II North and South.

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

The potential offshore wind farms are within the 240 km range of three Danish meteorological radars, as well as two Swedish and one German radar. This can have an effect on the radars such as blockage or disturbance. Further assessments are necessary and a dialogue with the Danish Meteorological Institute is recommended. The offshore wind farm is also within the range of two Swedish and one German weather radar. Dialogue with the Swedish weather institute (Meteorologiska och Hydrologiska Institut - SMHI) and German weather institute (Deutscher Wetterdienst - DWD) is also recommended.

Regarding radio communications, the planned areas for the Kriegers Flak II offshore wind farms 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 expected. Several Danish and Swedish offshore wind farms are either established or planned to be established in the area near Kriegers Flak II. With measures to mitigate effects, such as markings, layout and design of sites, and Digital Signal Processing, the impact can be reduced. These measures would be necessary for the future offshore wind farms, Kriegers Flak II included.

The result of this report is 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 Kriegers Flak II offshore wind farm'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 den planlagte havvindmøllepark i Østersøen, kaldet Kriegers Flak II (North and South). Projektet består af to områder (Nord og Syd) og er beliggende øst for Stevns og Møn. Det omfatter et samlet areal på 174 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 havvindmølleparken.

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.

Den nordlige havvindmøllepark ligger inden for høringszonen for to danske lufthavne og én svensk lufthavn. Det er derfor muligt at en påvirkning på disse radar opstår. Den nærmeste tyske lufthavn ligger med en afstand på mere end 60 km, som er udenfor høringszonen i Tyskland. På denne afstand vurderes det, at de tyske lufthavne og radar ikke vil blive påvirket under opførelsen, driften og afvikling af Kriegers Flak II (Nord og Syd).

Med hensyn til skibstrafik henviste de indledende kommentarer under HAZID-workshops til bekymringer vedrørende sikkerhed og navigation. Foranstaltninger som visuelle markeringer, placering af møller, angivelse af havvindmøllerne i søkort og supplerende kystnære radarer kan reducere mulige påvirkninger.

Den potentielle havvindmøllepark ligger inden for en 240 km rækkevidde af tre danske meteorologiske radarer, samt to svenske meteorologiske radarer og én tysk radar. Havvindmølleparkerne kan påvirke radarerne som blokering eller forstyrrelse. Yderligere vurderinger er nødvendige, og dialog med Danmarks Meteorologiske Institut (DMI) anbefales. Dialog med Sveriges Meteorologiska och Hydrologiska Institut (SMHI) og tyske Deutscher Wetterdienst (DWD) anbefales også.

Med hensyn til radiokommunikation har det planlagte område for Kriegers Flak II (Nord og Syd) 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. Der er flere danske og svenske havvindmølleparker, som enten er etableret eller planlagt i området nær Kriegers Flak II. Det er nødvendigt, at undersøge om mulige kumulative effekter kan opstå. 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 Kriegers Flak II, 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 Kriegers Flak II 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 Kriegers Flak II (North and South). 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 farms in the areas Kriegers Flak II (North and South). 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.

Kriegers Flak II North and South are 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, Kriegers Flak II 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 radars and radios is being carried out in a separate study.

3 PROJECT DESCRIPTION AND SCENARIOS

The Kriegers Flak II OWF comprises of two sites: a northern site covering an area of 99.3 km² and a southern site spanning 75.3 km² (174 km^2 in total) (Figure 3-1). A cable corridor is planned with landfall near Skørpinge Strand, as shown in Figure 3-1.

The northern site, Kriegers Flak II North, is 15 km from the nearest coast which is Stevns Klint. The Swedish EEZ border is approximately 16 km east of the planned OWF area.

The southern site, Kriegers Flak II South, is about 16 km from the coast, which is Møns Klint. The German EEZ border is approximately 39 km south 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 37 turbines). A base case scenario with a total capacity of 1 GW and an overplanting scenario with total capacity of 3,450 MW is also presented. Each scenario represents both the northern site and southern site, which means the number of WTGs is distributed as evenly as possible between the two sites. For example, in scenario 2 (

Table 3-2), 19 of the 37 WTGs are distributed in the northern site and 18 WTGs are distributed in the southern site.

The boundaries of the sites (north and south) are 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).

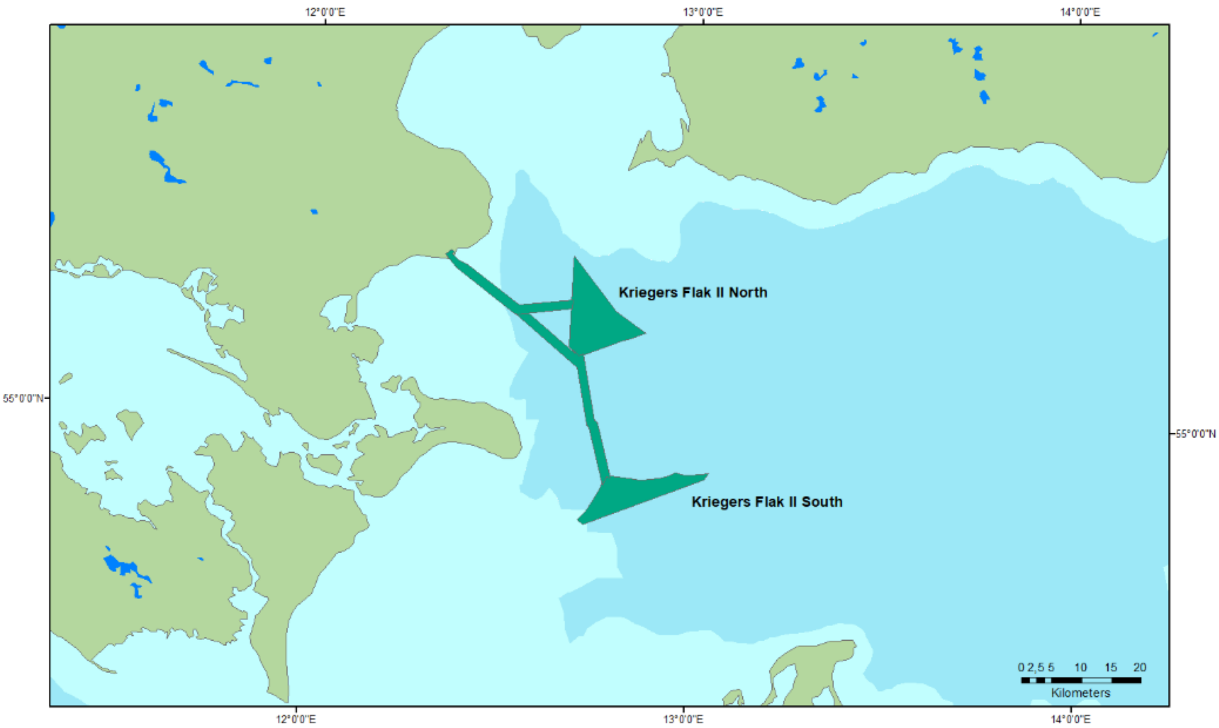

Figure 3-1 Map showing the two sites for buildout of offshore wind farms - Kriegers Flak II North and Kriegers Flak II South - and the export cable corridors making a common landfall on the south coast of Stevns site. The exemplified site layout for Kriegers Flak II North and South will consider four scenarios shown in Figure 3-2.
Source: Energinet, 2023

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 Kriegers Flak II North & South layout scenarios. WTG: wind turbine generators. MSL: Mean Sea Level. Source: Cowi, 2023.

	Wind farm capacity (GW)	WTG capacity (MW)	No of WTG
Scenario-01	1	15	67
Scenario-02	1	27	37
Scenario-03	3.45	15	230
Scenario-04	3.45	27	128

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 3,450MW.

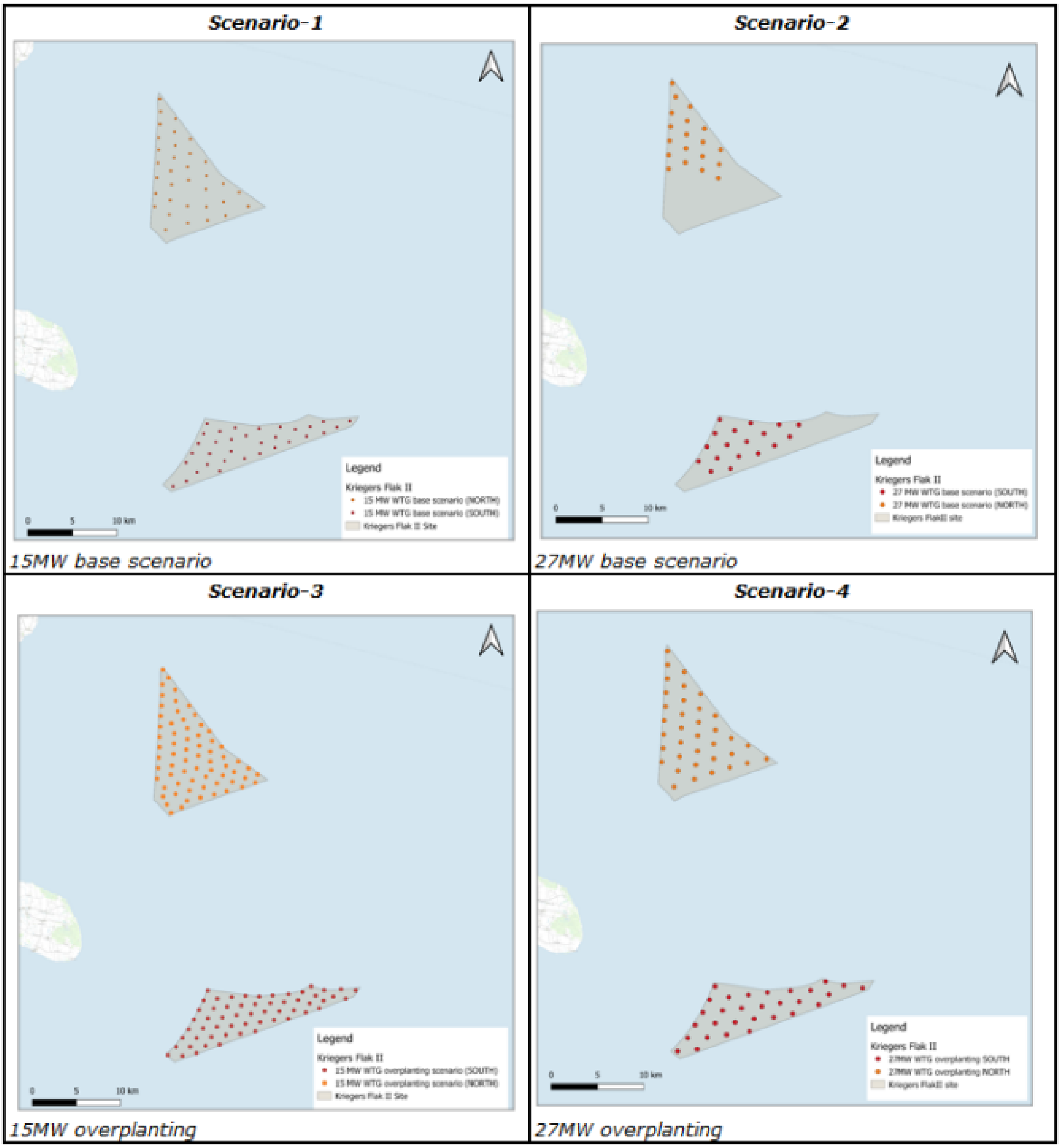

Figure 3-2 Four scenarios derived from layout report. Overplanting scenario: installing more wind turbines than necessary to meet the demand. Base scenario: Installing wind turbines based on average demand and expected wind conditions. Source: **(COWI, 2023)**.

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 Kriegers Flak II (North and South). 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 Kriegers Flak II (North and South) 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 areas - Kriegers Flak II North and South - have been provided by Energinet.

The evaluation of cumulative impacts involve 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 Kriegers Flak II North and South.

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 Kriegers Flak. This is planned to be decommissioned (Figure 5-1) (DFS, N/A).

5.1.1.1 Danish aviation Facilities

Kriegers Flak II North is within the 60 km consultancy zone (høringszone) of both Roskilde and Kastrup airport (Figure 5-1). The Kriegers Flak II North and South are situated within the operational range of the Stevns and Møns airports radars, which are smaller aviation facilities and does not have a consultancy zone (Figure 5-1). The OWF sites are placed outside the 15 km wind farm exclusion zone for proximity to airports (Figure 5-1).

5.1.1.2 Adjacent countries

The closest airport in Sweden which has a MSA zone is Malmö airport. This is about 53 km away (Figure 5-1). (Transportstyrelsen).

At the present time the closest airport in Germany near Rügen is 64 km away. Rostock Airport is the nearest larger airport about 107 km away from Kriegers Flak II South (Figure 5-1) (Bundesaufsichtsamt für Flugsicherung, 2023; DFS, N/A).

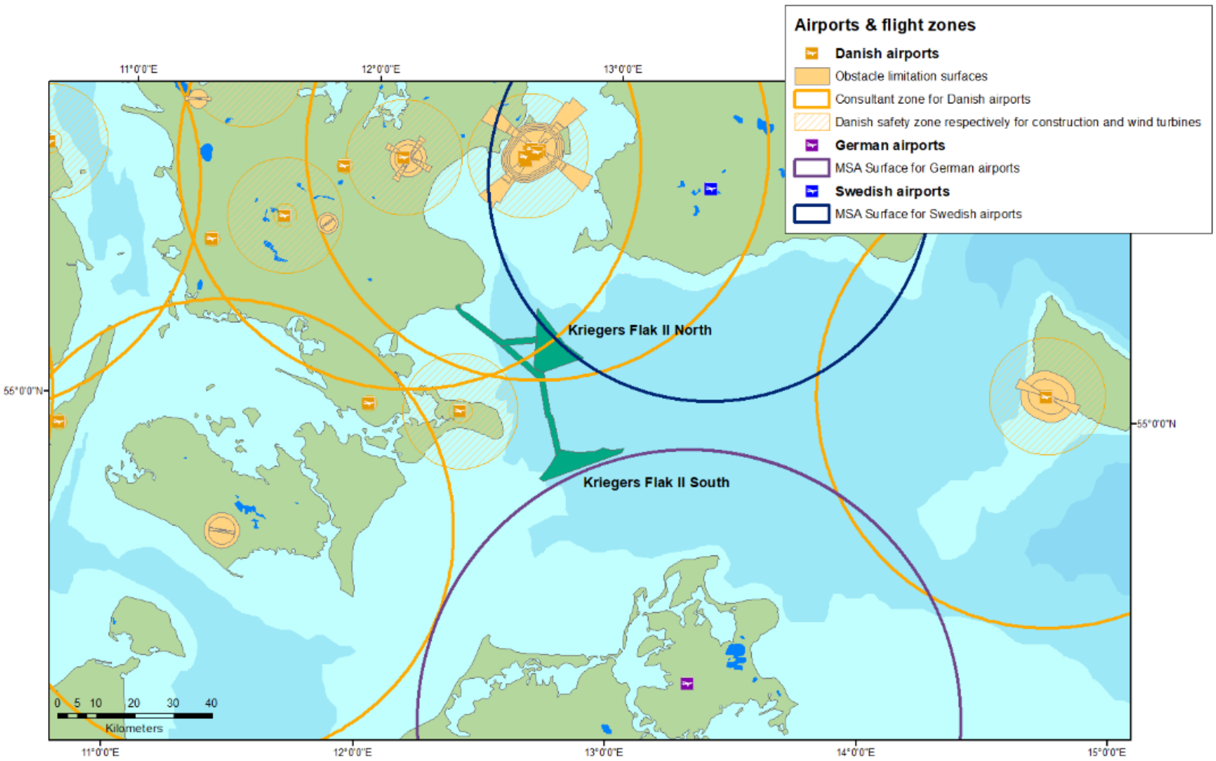

Figure 5-1 Airports and flight zones. Sources: Energinet, 2023; Plandata.dk, 2023

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). Kriegers Flak II North and South are placed outside the main routes for all types of vessels. (DNV, 2024)

Wind turbines can result in potential impact with blocking or reflecting radar signals (see ch. 6.1). A HAZID workshop has 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 ch. 5.1.2.1.

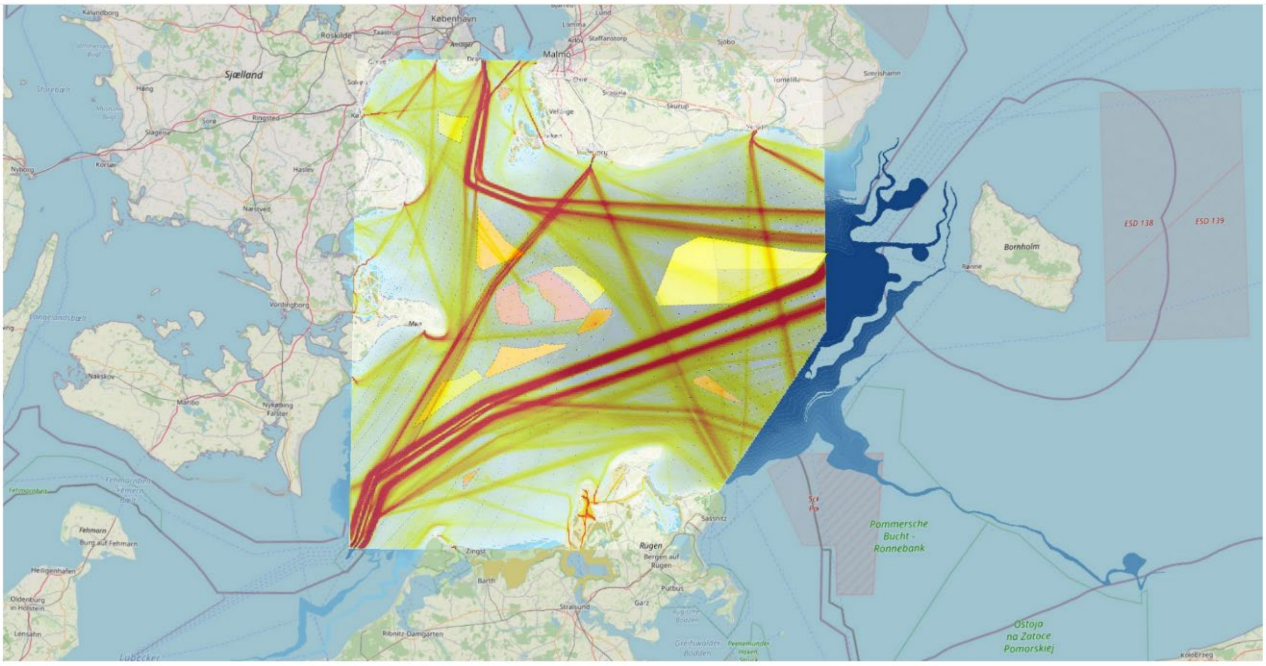

Figure 5-2 Vessel routes based on AIS data from 2022. Kriegers Flak II North and South are shown as orange.
Source: HAZID Report Kriegers Flak II **(DNV, 2024)**

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 Kriegers Flak II North and South offshore wind farm will not be covered in this study, but in a separate study on none-civilian radars.

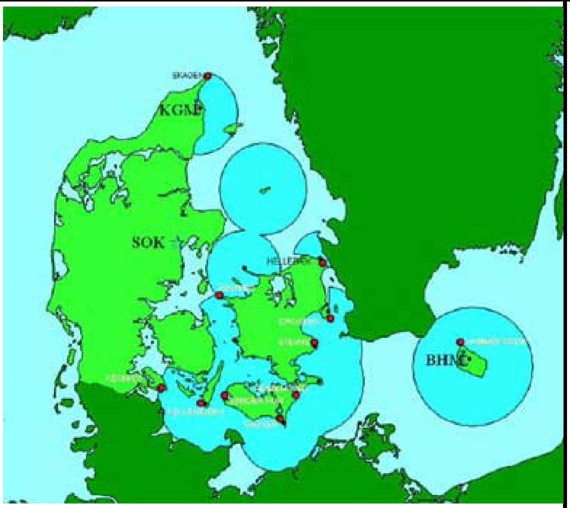

Figure 5-3 Radar stations before KYRA project in 2000-2004. Sources: Danish Naval History (Kystradarprojektet (KYRA)), 2007.

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 Kriegers Flak II North and south sites are situated within the operational scope of the Stevns, Virring and Bornholm meteorological radar (Figure 5-5).

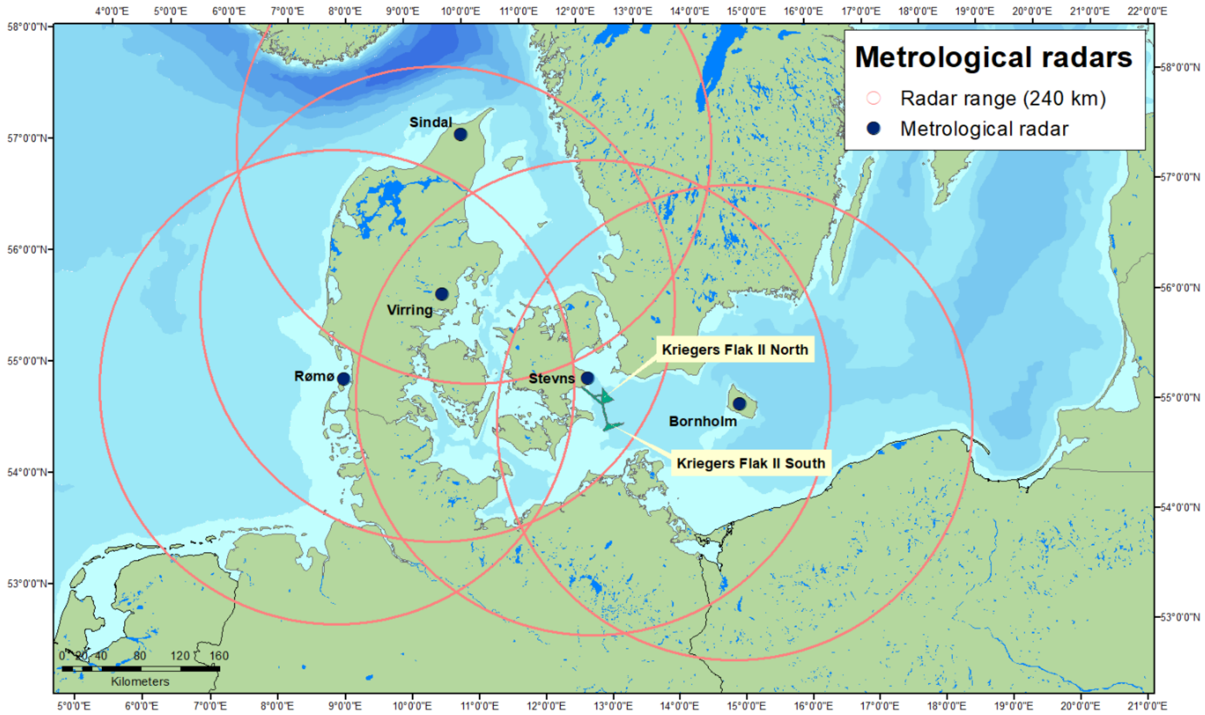

Figure 5-5 The five meteorological radars in Denmark, showing a range of 240 km. Source: DMI, 2023; Energinet, 2023.

Table 5-1 Location and metadata concerning Danish DMI's 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 nearest meteorological radar is near Ängelholm which is about 125 km away from the Kriegers Flak II North (Figure 5-6) (Norin, Researhgate, u.d.).

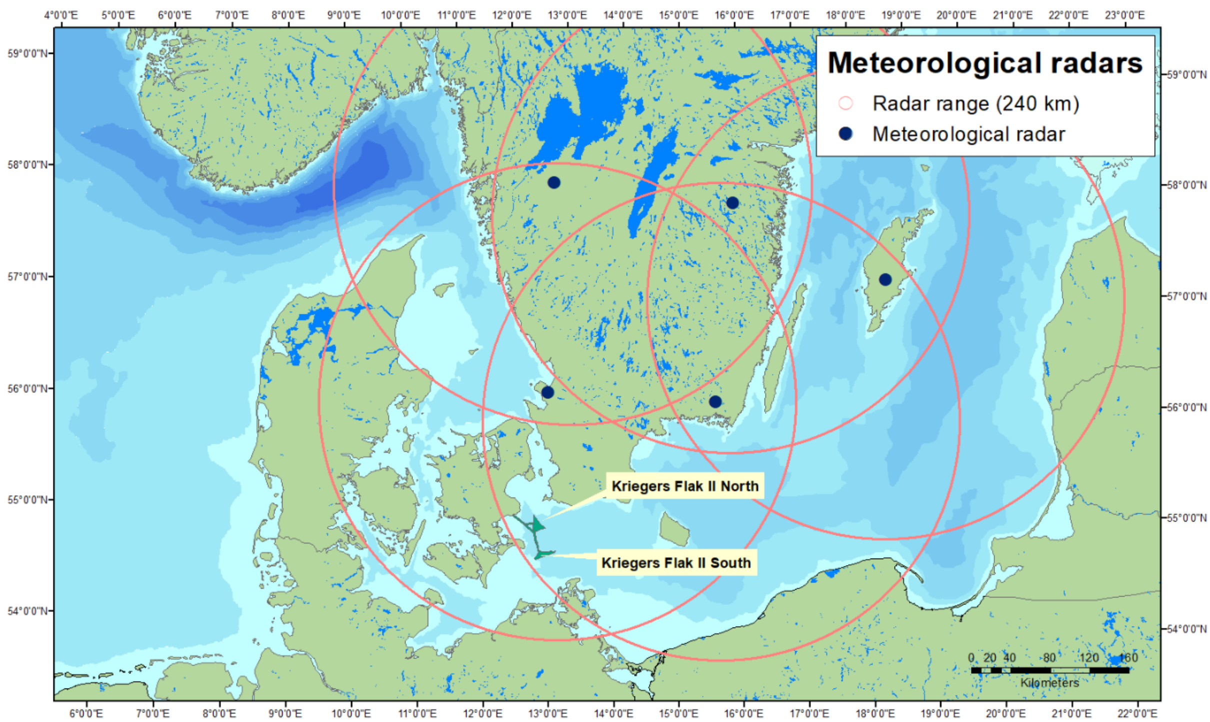

Figure 5-6 The relevant meteorological radars in Sweden, showing a range of 240 km Source: SHMI, 2023; Researchgate,N/A; Energinet, 2023

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 (Wetterdienst, 2017). A radar in Rostock covers the area of Kriegers Flak II North and South (Figure 5-7).

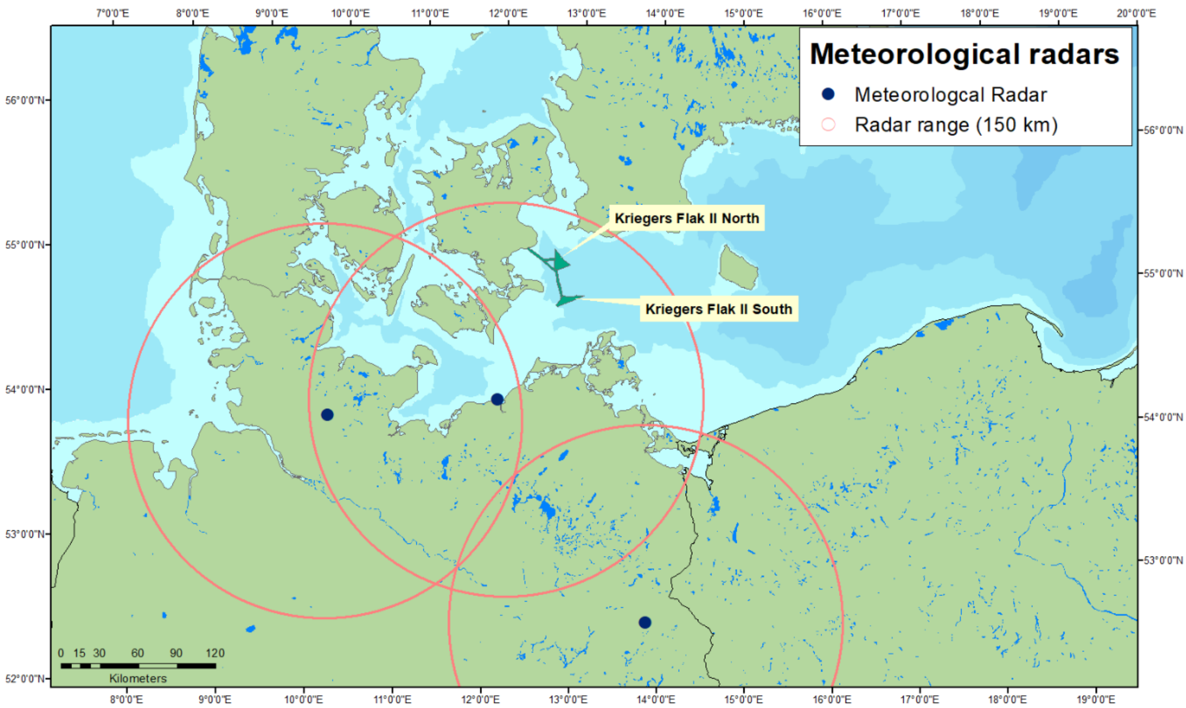

Figure 5-7 The relevant meteorological radars in Germany with a 150 km radius. Source: DWD, 2017; Energinet, 2023

Table 5-5-3 Location and metadata concerning German Weather Service (DWD) radar stations. Source: **(Wetterdienst, 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

DNV

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 Kriegers Flak II North and South areas 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 (NIRAS, 2022).

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 Kriegers Flak II North and South

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 Kriegers Flak II North and South.

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 Kriegers Flak II North and South the tallest wind turbine in the four layout scenarios are 330 meters (37 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

The Kriegers Flak II North is within the consultation zone for both Roskilde and Copenhagen Airport (60 km) (Plan- og landdistriktsstyrelsen). The MSA surface (55 km) of the Swedish airport of Malmö overlaps with small part of the eastern part of the northern site as well (Figure 5-1). Dialogue with these airports and the potential effects on the three airports 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.

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.

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).

In 2015 an area adjacent to Kriegers Flak II (North and South) was assessed by NIRAS for Energinet.dk (NIRAS, 2015). In this report it was concluded that potential impact on vessels is possible. A navigational safety and risk assessment (HAZID) has been performed for Kriegers Flak II North and South, simultaneously of this report. In the preliminary study, comments during HAZID workshops raised concerns regarding safety and navigation. The results from the HAZID will is reported in 2024 (DNV, 2024).

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 effect 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. Kriegers Flak II North and South are within Virring, Stevns and Bornholm meteorological radar range with the closest radar (Stevns) being approximately 17 km away form Kriegers Flak II North. 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 Kriegers Flak II North and South areas are within the LOS of Virring, Stevns, and Bornholm meteorological radar range and potential impacts, like interference, 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). The offshore wind farm is also within the range of two Swedish and one German weather radar. An early dialogue with the Swedish weather institute (Meteorologiska och Hydrologiska Institut - SMHI) and German weather institute (Deutscher Wetterdienst - DWD) is also recommended.

6.2.4 Radio chains

There are currently no point-to-point radio chains in or near Kriegers Flak II North and south and South. 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

Several offshore wind farms are established in close vicinity to Kriegers Flak II North and South and several are planned to be established (Figure 7-1).

In Denmark, Kriegers Flak I is an existing OWF which consists of two sites placed between Kriegers Flak II North and South. Additionally, sites such as Lillgrund, EnBW Baltic 2, EnBW Baltic 1 and Arcadis Ost 1 are other existing OWF in the larger area surrounding Kriegers Flak II.

Kriegers Flak is a Swedish OWF planned to border the eastern site of Kriegers Flak I. A larger Swedish OWF area consisting of three sites (Triton, Skåne, and Arkona) is located between Bornholm and Kriegers Flak II North and South. During the analysis of potential cumulative impacts Kadetbanke was considered. However. the DEA has since decided that the project should not be further developed. It will therefore not cause any cumulative impacts.

If additional offshore wind farms are established in the Baltic Sea, it may alter radar operations in Denmark's maritime and aerial territories. It is possible that establishment of Kriegers Flak II and additional offshore wind farms might lead to negative cumulative impacts. This should be further assessed in an environmental impact assessment after the project specifics are set.

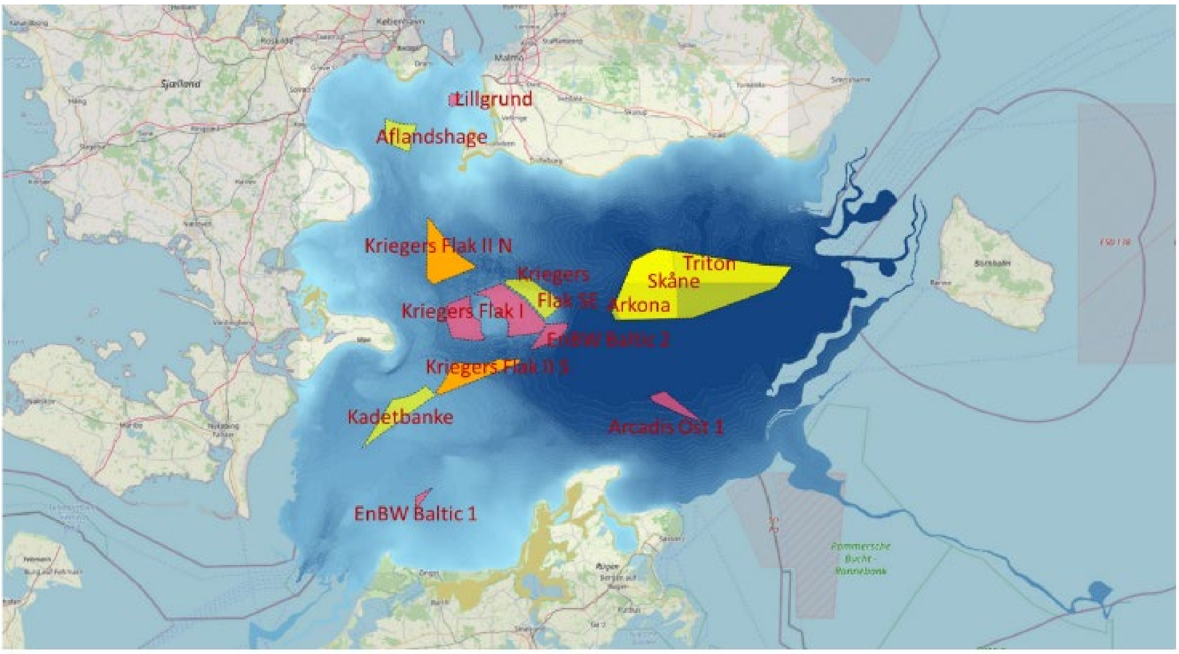

Figure 7-1 Established and planned offshore wind farms in the Baltic Sea. Orange areas: Kriegers Flak II, red areas: existing parks, yellow: planned to be established. Source: HAZID report Kriegers Flak II **(DNV, 2024)**

8 MITIGATION MEASURES

Offshore wind turbines offer significant benefits to combat climate changes by delivering 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).**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).
3. **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).
4. **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).
5. **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).
6. **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 farms to be installed in Kriegers Flak II (North and South) 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 Kriegers Flak II North and South are 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
Germany	Aviation	Bundesaufsichtsamt für Flugsicherung
	Aviation	Deutsche Flugsicherung (DFS)
	Meteorological Radar	Deutscher Wetterdienst (DWD)

10 REFERENCES

(ICAO), T. I. (2009). Quality Assurance Manual for Flight Procedure Design. Retrieved from https://www.icao.int/Meetings/PBN-Symposium/Documents/9906_v2_cons_en.pdf

Atlassian. (2023, 11 24). DMI’s Weather Radar Data. Retrieved from https://confluence.govcloud.dk/display/FDAPI/Radar+Data

Balsved, J. E. (2007, 05 13). Kystradarprojektet (KYRA). Retrieved from https://www.navalhistory.dk/Danish/Vaaben/Udvikling/Kystradarprojekt.htm

Bundesaufsichtsamt für Flugsicherung. (2023). Anlagenschutzbereiche nach §18a nach LuftVG.

CanWEA, RABC. (2020, 02 06). Technical Information and Coordination process between wind turbines and radio communication and radar systems.

COWI. (2023, 02 15). Mere Havvind 2030 Kriegers Flak II and Kattegat II - Wind farm layouts. Energinet.

Danish Business Authority. (n.d.). Vejledning i at undersøge, om der er udstedt frekvenstilladelser til radiokædeforbindelser i et givet geografisk område. Retrieved 11 2023, from https://sdfi.dk/Media/637967609694517831/vejledning_i_at_undersoege_om_der_er_udstedt_frekvenstilladelser_til_radiokaedeforbindelser_i_et_givet_geografisk_omraade.pdf

DFS, D. F. (N/A). This is how DFS promotes Wind Energy. Retrieved 11 28, 2023, from https://www.dfs.de/homepage/en/environment/wind-energy/

DMI. (n.d.). Radar. Retrieved from https://www.dmi.dk/dmis-vejrprodukter/radar

DNV. (2024). *HAZID report Krieger Flak II - Marine Environmental Studies.* Energinet Eltransmission A/S.

Energinet.dk, NIRAS. (2015, 04). Vesterhav Nord Havmøllepark. VVM-redegørelse og miljørapport.

Energistyrelsen. (2021, 12 08). Frekvensstrategi 2021 - Prioriteter i Energistyrelsens krekvensadministration. Retrieved from https://ens.dk/sites/ens.dk/files/Tele/frekvensstrategi_2021.pdf

Energistyrelsen. (2022). Frekvensplan 2022. Retrieved from https://ens.dk/sites/ens.dk/files/Tele/frekvensplan_0_0.pdf

Energistyrelsen. (n.d.). Kriegers Flak II Havvindmøllepark. Retrieved 11 2023, from https://ens.dk/ansvarsomraader/vindmoeller-paa-hav/udbud-af-havvindmoelleparker/kriegers-flak-ii-0

EUROCONTROL. (2014, September). How to Assess the Potential Impact of Wind Turbines Surveillance Sensors.

NIRAS. (2015, 10). Radaranlæg og radiokæder - VVM-redegørelse for Kriegers Flak Havmøllepark Teknisk baggrundsrapport. Energinet.dk. Retrieved from https://ens.dk/sites/ens.dk/files/Vindenergi/kriegers_flak_havmoellepark_vvm_radar_og_radiokaeder_baggrundsrapport.pdf

NIRAS. (2022, 06 24). Hesselø Offshore Wind Farm - Radar and radio interference. Energinet Eltransmission A/S. Retrieved from https://ens.dk/sites/ens.dk/files/Vindenergi/213_hesseloe_owf_radar_and_radio_interference_final_draft_20220623_2.pdf

Norin, L. (2017, 05 10). Wind turbine impact on operational weather radar I/Q data - characterisation and filtering. Copernicus Publications. Retrieved from https://www.semanticscholar.org/reader/20fce824fe1a9aab1face96daf3a355974ae5817

Norin, L. (n.d.). *Researhgate.* Retrieved from https://www.researchgate.net/figure/Listing-of-weather-radar-stations-over-Sweden_tbl1_261000986

Omar Abu Ella, Khawla A. Alnajjar. (2022). *Mitigation Measures for Windfarm Effects on Radar Systems.* Hindawi - International Journal of Aerospace Engineering.

Plan- og landdistriktsstyrelsen. (n.d.). Retrieved 11 2023, from https://kort.plandata.dk/spatialmap

SMHI. (2023, 5 3). Radar - Höjdbaserad Nordenkomposit. Retrieved from https://www.smhi.se/kunskapsbanken/meteorologi/radar/radar-hojdbaserad-nordenkomposit-1.195511

Trafikstyrelsen. (2023, 08 21). Flyvepladser og planlægning. Retrieved from https://www.trafikstyrelsen.dk/arbejdsomraader/luftfart/flyvepladser/flyvepladser-og-planlaegning

Trafikverket. (2014, 02 06). Vindkraft och civil luftfart. Retrieved from https://trafikverket.diva-portal.org/smash/get/diva2:1363995/FULLTEXT01.pdf

Transportstyrelsen. (n.d.). Godkända/certifierade instrumentflygplatser. Retrieved 11 28, 2023, from https://www.transportstyrelsen.se/sv/luftfart/flygplatser-flygtrafiktjanst-och-luftrum/Svenska-flygplatser1/Godkandacertifierade-instrumentflygplatser/

U.S Department of Energy. (n.d.). Mitigating Wind Turbine Radar Interference. Retrieved from https://www.energy.gov/eere/wind/mitigating-wind-turbine-radar-interference#:~:text=Wind%20turbines%20can%20cause%20interference,and%20impeding%20critical%20weather%20forecasting.

Wetterdienst, D. (2017, 09). Wetter und Klima aus einer Hand. Retrieved from https://www.dwd.de/SharedDocs/broschueren/DE/presse/wetterradar_pdf.pdf?__blob=publicationFile&v=7

Wind Exhange - U.S. Department of energy. (n.d.). Wind Turbine Radar intereference. Retrieved 11 2023, from https://windexchange.energy.gov/projects/radar-interference

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.