Final report

1. Project details

Project title	Radar Controlled Obstruction Lights at the National Test Centre in Østerild
Project identification (program abbrev. and file)	Journal no.: 64014-0563 (Internal Project ID = CORAL)
Name of the programme which has funded the project	EUDP 14-II
Project managing company/institution (name and address)	Terma A/S
Project partners	DTU Wind Energy Aalborg university
CVR (central business register)	41881828
Date for submission	31-12-2018

1.1 Short description of project objective and results

UK version

The purpose of the CORAL project has been firstly to evaluate the technical Radar Control of Obstruction Lights solution in Østerild and based thereof derive generic system requirements with the clear aim of formulating recommendations for a Danish regulatory. Secondly to investigate the effects of introducing Radar Controlled Obstruction Lights on local residents by conducting surveys in the local community before and after the installation of the radar at Østerild test centre.

The result of the technical evaluation has verified the solution and provided solid system knowledge enabling the formulation of draft Danish Obstruction Light Control regulatory recommendations.

The result of the social impact evaluation shows a general improvement on most of the investigated topics mitigating the light pollution at the test centre, though without the statistical data being conclusive. Furthermore, main recommendations in communication of an OLC solution being installed in communities have been identified.

DK version

Formålet med CORAL-projektet har været først at evaluere den tekniske radarstyring af hindringslyset i Østerild, og på baggrund heraf udarbejde generiske systemkrav, der kan danne grundlag for et dansk regelsæt på området. Dernæst at undersøge virkningerne af indførelsen af radarstyret markeringslys på lokale beboere ved at foretage undersøgelser i lokalsamfundet før og efter installationen af radaren på testcenteret i Østerild.

Resultatet af den tekniske evaluering har verificeret løsningen og givet solid systemforståelse, der muliggør formulering af udkast til et dansk regelsæt for OLC systemer.

Resultatet af evalueringen af de sociale konsekvenser viser en generel forbedring på de fleste af de undersøgte emner, der afhjælper lysforurening omkring test centeret, dog uden at de statistiske data er repræsentative. Derudover er der blevet identificeret hovedanbefalinger til kommunikationsmetodik ved etablering af OLC-løsninger i nærmiljøet.

1.2 **Executive summary**

When it was decided to establish the radar control of the aviation lights at the National Test Centre in Østerild, this was categorized as a pilot/test installation, acknowledging some challenges getting the OLC system installed, tested, verified and approved for operational use. Apart from some minor technical issues the far most severe challenge was to obtain formal approval. As no formal regulatory exists an exemption from BL 3-11 was granted from the Danish Transport, Construction and Housing Authority in agreement with the Danish Defence Command.

Both in the test and verification process and in other specific customer projects valuable experience and system knowledge has been gathered to optimize and finalize the OLC product solution for being offered to the wind industry.

Furthermore, we have obtained a good understanding of the requirements for OLC systems, which also are the basis for the draft Danish OLC regulatory set forth in this report.

Additionally, we have currently obtained OLC authority approval in both Germany and US, as these nations are the only one having a formal regulatory. Furthermore, the first 2 system are in operation in Germany today and 10 more system are under contract to go operational during 2019.

On this basis, it is fair to say, that the Østerild project has been a true enabler for bringing Terma in a very good market position concerning radar-controlled aviation lights.

Considering the environmental and social impacts, it can generally be concluded that the OLC system helped to reduce local residents' awareness of and annoyance by the obstruction lights.

Looking further ahead, several nations are currently drafting OLC regulatory by push from local wind industry and in this situation, it is very convincing that Terma is able to provide such national authorities with technology from proven operational OLC radar systems.

Acknowledgement

We would like to thank both DTU and AAU for a very good project effort and we would like to direct a special appreciation to DTU Østerild operational staff for a tremendous effort and patience supporting all tests, trials and meetings conducted at their facilities at the National Test Centre. A special appreciation to the EUDP secretariat for their a good cooperation and for handling the funding for the project.

1.3 Project objectives

1.3.1 Pre-requisite.

The project starts from the point where the installation and commissioning of the radar based OLC system has taken place. In addition, to support the second objective of evaluating community views, preliminary information will be gathered and analysed. Furthermore, a communication plan will be prepared.

1.3.2 Work Package 0:

General project management package for executing the project.

1.3.3 Work Package I:

The starting point of this phase is to quantify the detailed performance of the equipment in order to able to fine-tune the equipment towards this specific application. This will be done by means of defining a series of test looking at different target types and target sizes flying in different trajectories in various weather conditions. This will be done using the default antenna type and antenna deployment in installed system, but alternative antenna types and deployment will also be considered.

Once the test specification has been finalized and proper documented, the specified test will be carried out and documented in a thorough manner.

1.3.4 Work Package II

Utilizing the test result from WP I, the objective for this phase is derivation the minimum system requirements for a 'Wind Farm Obstruction Lights Control' solution. These will focus on additional system parameters compared to those of WP I, such as minimum detection and warning range. Also, the balance between clutter (noise) level and false alarm rate will be looked at. Finally, more back-end parameters such as requirements to logging/reporting levels and general system accessibility levels capabilities will be addressed.

If for some reason any of these general system requirements identifies some demands for corrections/improvements, mitigation to such will be considered.

1.3.5 Work Package III:

With the established minimum OLC system requirements specification the objective of this WP is to prepare a standardization/recommendation for Radar based OLC systems. This activity might require input or peer review activity from external subject matter experts.

1.3.6 Work Package IV:

Utilizing the results from WP II and III this WP will examine the environmental and social effects of introducing Radar Control of Wind Farm Obstruction Lights. This task will be accomplished by assessing the nature of the problem and then conducting before and after evaluations regarding the social acceptance of introducing a Radar based OLC system and thereby reducing the time where the lights are on.

Measurement of the specific obstruction light time reduction will be documented. This WP will be coordinated with all parties, including the Aviation Authority and the Test facility management, in order to ensure safety and reliability of the radar system throughout the test phases. The design and analysis of the evaluation protocols/questionnaire and associated research in this phase will be conducted by The Danish Centre for Environmental Assessment at AAU (Aalborg University Denmark), in collaboration with DTU Wind Energy, using well establish scientific tools and external peer review as appropriate. The project partners aim at developing interview protocols and analytical procedures that follow rigorous scientific standards to support publication of the results in peer reviewed journals.

1.3.7 Work Package V

Disseminate results to relevant stakeholders as outlined in the communication plan.

2. Project results and dissemination of results

2.1 WP1: Test and verification of the Installation in Østerild

2.1.1 Overall Description of the Østerild OLC system

The system concept in the OLC solution is based on one or more radar sensor units performing the surveillance of the area around the wind farm and providing information to the central Light Controlling System (LCS) server. The central LCS controls the local WTG light controller equipment, including the aviation lights, normally required by national regulations within the wind farm.

A general system overview can be seen in below figure.

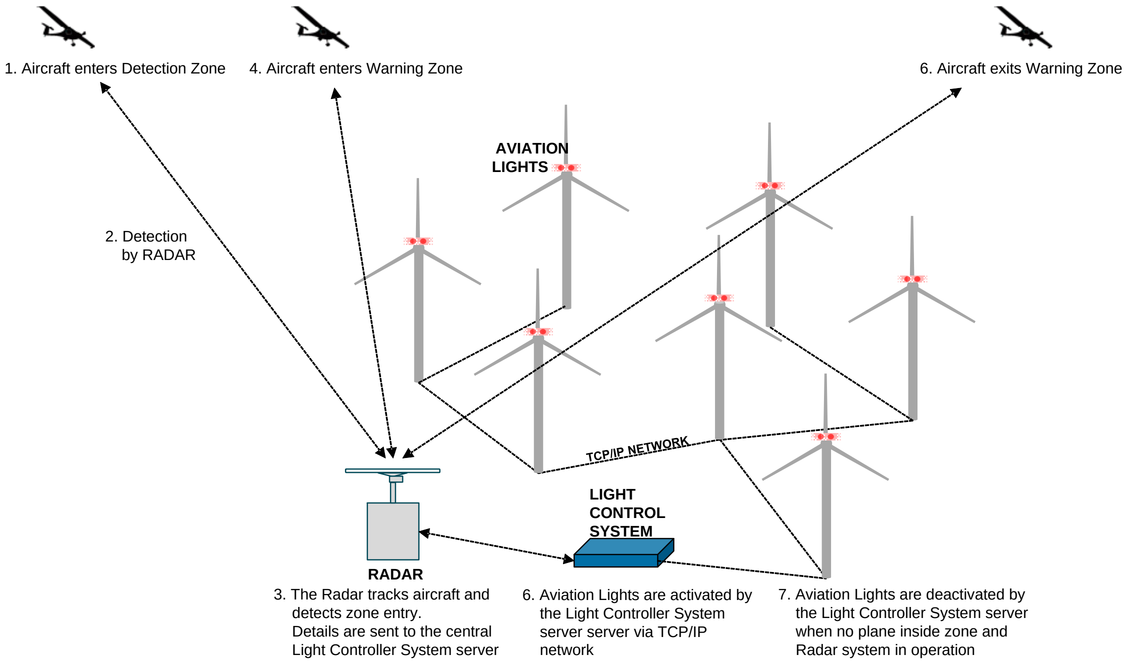


Figure 1 System Overview

The SCANTER radar system can be deployed in a way that full radar coverage is provided throughout the wind farm area. This will ensure that the aviation lights switch on and thereby maintain aviation safety.

The Radar based OLC system components are deployed at the National Test Centre in Østerild as shown in Figure 2.

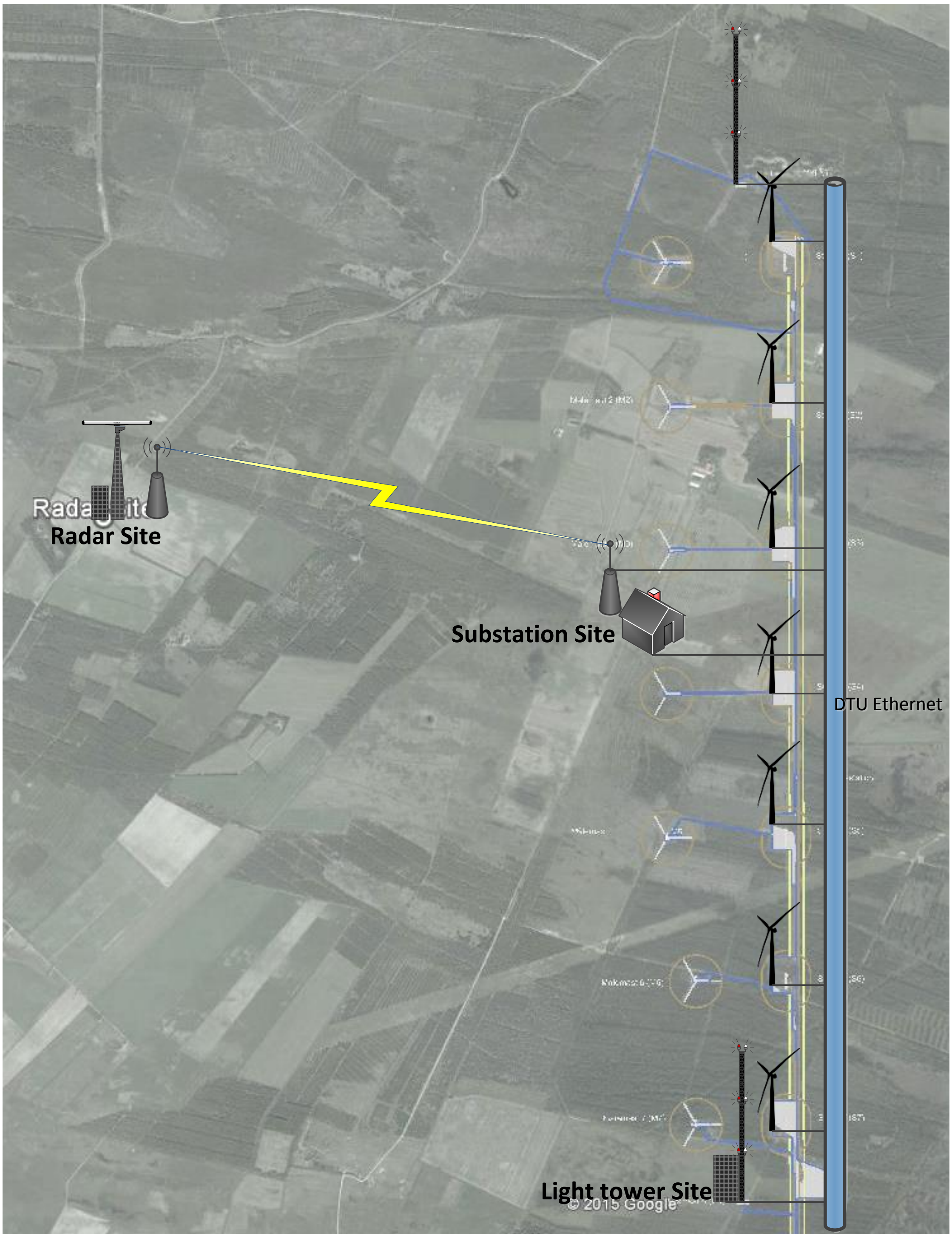


Figure 2 System overview – physical view - Østerild

A conceptual block diagram for the Østerild installation is shown in Figure 3.

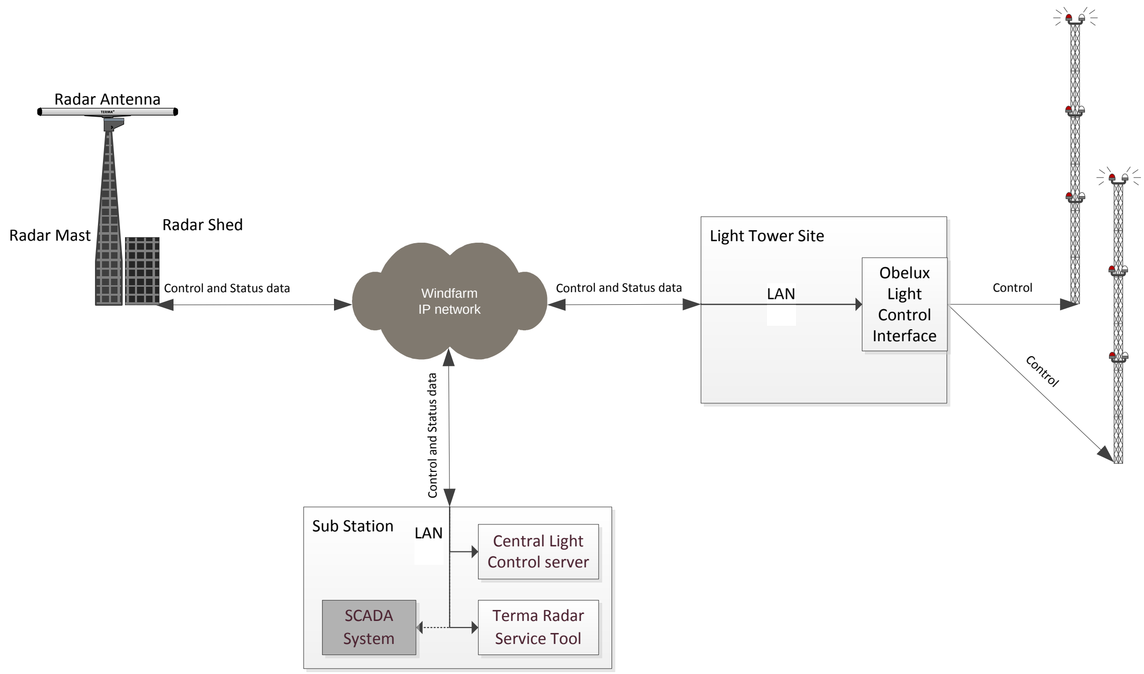


Figure 3 System overview - logical view

The Radar Site, the Sub Station Site and the Light Tower Site holding the interface to the two light towers are interconnected via the customer communication infrastructure. In the Østerild case, this is implemented by a combination of fibre optic cables, copper cables and Line of Sight (LoS) wire-less equipment. Furthermore, in the Østerild case, the two light towers are existing equipment interfaced through the Obelux Light Control interface residing in one of the tower sheds.

The solution is prepared for interfacing to overlaying wind farm SCADA system, if applicable. A remote monitoring and notification system will be installed as part of a service level agreement entered August 2018.

2.1.2 Initial System requirements

At the time of entering the agreement with DTU on the Østerild project, no formal national requirements were available for defining the overall system requirement for this first of kind OLC installation at the National Test Centre in Østerild. The initial driver for the establishment of an OLC system was mainly political driven and the whole setup should be categorized as a test installation. However, setting the Test Centre into operation would still require a formal approval by the proper authorities. Hence a set of system requirement had to be defined, which is described in the following. The actual approval method is also described further down.

2.1.2.1 System overview considerations

To provide ample warning for air traffic, the obstruction lights must turn on in time for the pilot to observe the lights. This is projected into a warning zone, the size of which depends on the required warning time and speed of the aircraft.

Furthermore, the radar must have good and reliable detection of the aircraft before reaching the warning zone. Hence, there is a need for a radar detection area surrounding the warning zone. This determines the required coverage area and instrumented range of the radar:

Wind Farm Area: Area populated with wind turbines

Warning Zone: Obstruction lights turn on when an aircraft enters this area and re-main lit while any aircraft is within this area. When (all) aircraft have left the area, obstruction lights turn off (standby) after a pre-set delay.

Detection Area: All aircraft within this area must be detected and tracked by the radar. This, combined with the radar location, determines the minimum required instrumented range of the radar.

2.1.2.2 Flight Safety Considerations

Flight safety considerations with respect to warning zone, detection ranges etc. have been made based on the basic Visual Flight Rules (VFR) weather minima, i.e. in Visual Meteorological Conditions (VMC), as specified by ICAO (<Ref1>). Initial calculations have been performed for a small aircraft (type Cessna 150). The relevant data used for calculation are listed in below table.

Minimum size aircraft (Radar Cross Section (RCS) in X-Band)	4 m2
Maximum airspeed of aircraft (below 3000 ft.)	250 kts
Minimum visibility (activation range)	5000 m

Table 1 Generic system parameters for ICAO.

In case that no additionally minimum requirements are stipulated by nations, these generic data will apply.

Calculations for a type Cessna 150 aircraft (4 m^2 RCS) have been performed for no rain (0 mm/h), light rain (4 mm/h) and heavy rain (8 mm/h) conditions.

As for the system design, the overall radar coverage calculations are conservatively based on the most severe of the detection requirements.

2.1.2.3 Warning zone

The regulatory work (<Ref2> and <Ref3>) does not mention the option of radar control of the obstruction light. Hence, the option of switching obstruction lights on wind turbines off when no aircraft is in the vicinity will be an exemption from existing regulations. <Ref1> states that the safety zone for high-intensity obstruction lights is a minimum distance of 5 km from the wind farm and light towers. With the addition of a 10 % margin, the obstruction lights will turn on when the aircraft is at 5.5 km distance from the wind farm.

An aircraft heading directly toward the wind farm with the maximum allowed airspeed (250 knots) will cover a distance of 5.5 km in 43 seconds.

Hence, the minimum warning time for the pilot will be 43 seconds.

Warning Zone (distance from Wind Farm Area) **5.5 km**

2.1.2.4 Detection Area

A detection zone outside the warning zone is required for the radar to detect an aircraft and to create and maintain a stable track on the aircraft. For this application, a detection zone of 3.7 km is required.

Detection Area (distance from Warning Zone) **3.7 km**

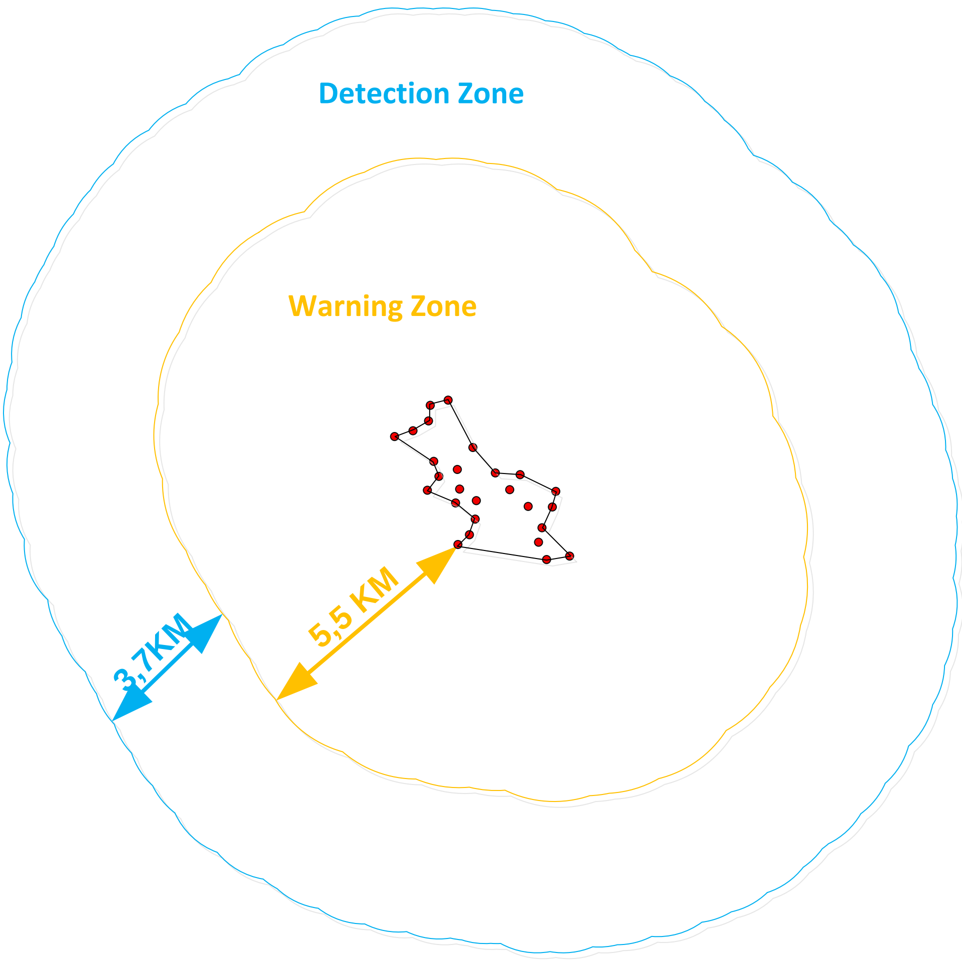


Figure 4 Zone definitions for generic wind farm.

2.1.2.5 Radar location / Instrumented range

With the zones defined in the previous section, an instrumented range of approx. 18.5 km will be sufficient to comply with detection requirements. As shown in Figure 2, an instrumented range of approx. 18.5 km allows for some flexibility with respect to location of the radar.

Also, in Figure 2, the area available for radar location is marked in blue. This area only takes into account the radar coverage based on range and does not consider issues like shadowing and blanking areas due to Line-of-Sight (LoS) problems caused by vegetation, structures etc. Hence, there may be locations within the area marked in blue, which are unsuitable for placing the radar. Such issues can only be determined by a site survey.

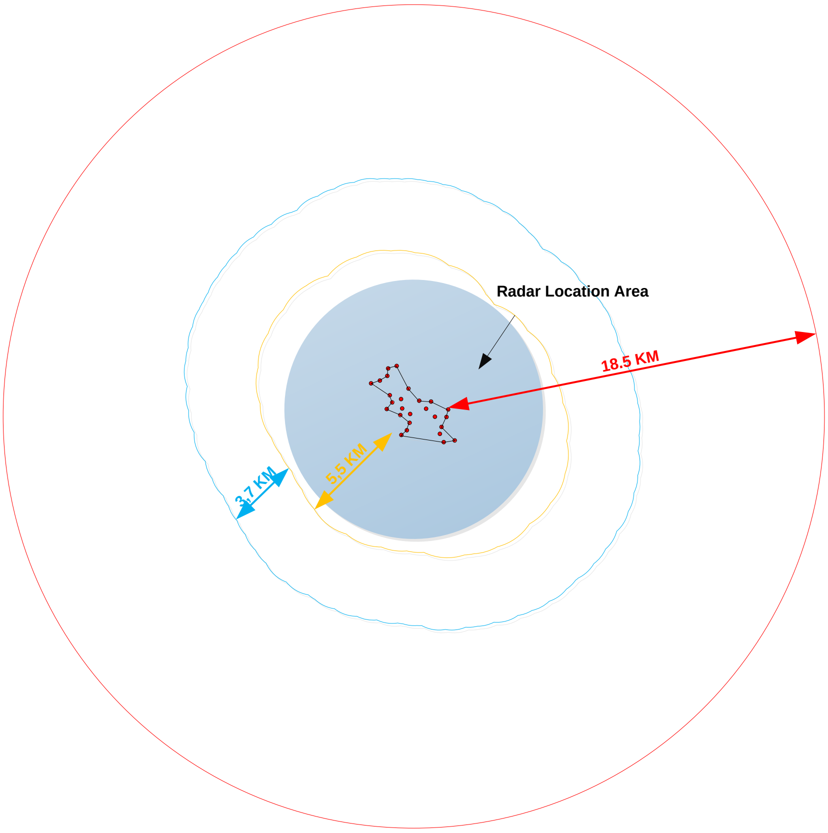


Figure 5 The blue area indicates possible locations for the radar.

2.1.2.6 Line of sight

Initially, a desktop analysis and subsequently a site survey of Line of Sight (LoS) issues have been performed.

Within the radar location area in the Østerild area, more locations have been selected based on terrain data and LoS coverage for a target flying in an altitude of 150m above ground level simulated.

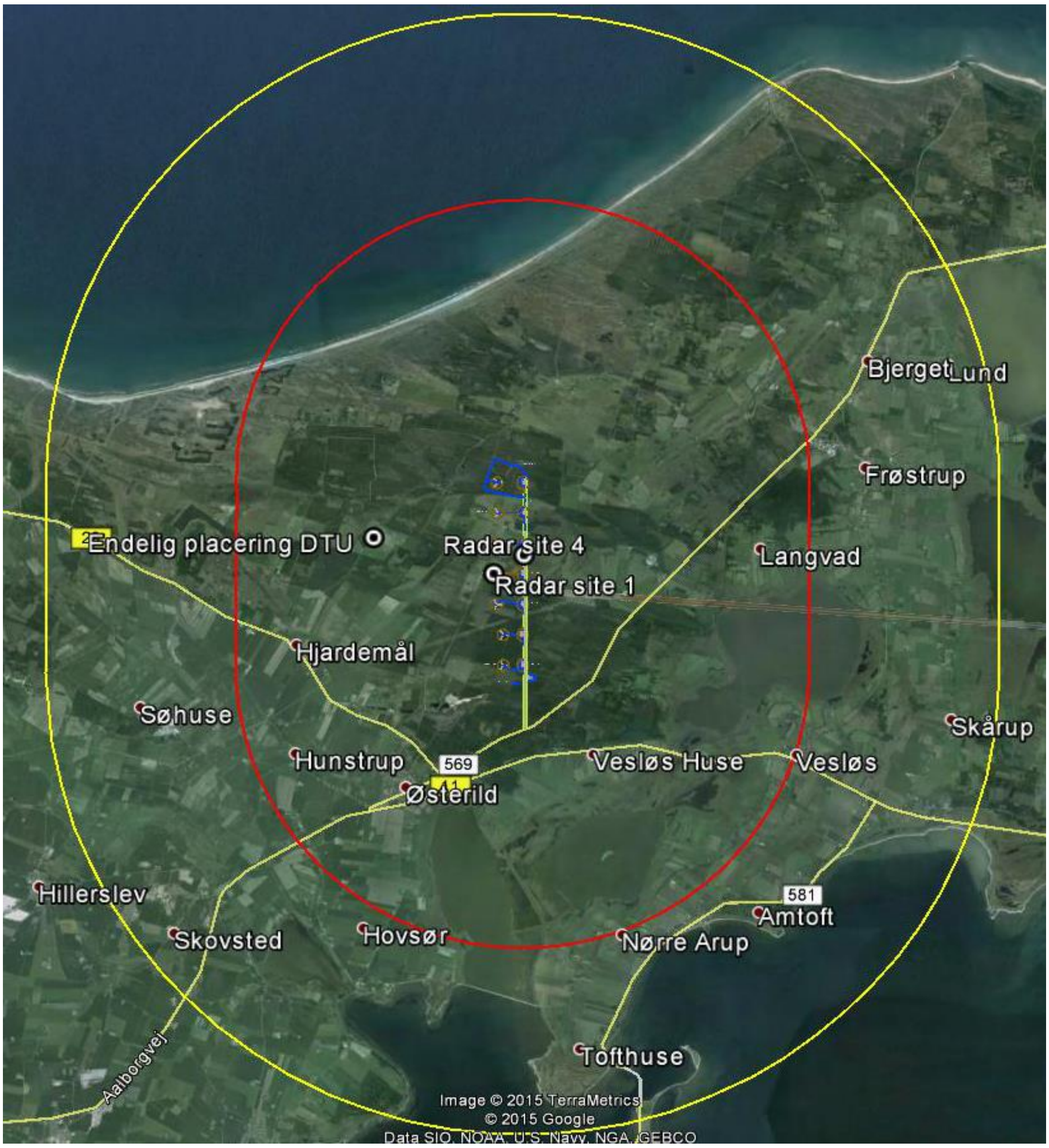


Figure 6 Final radar placing.

The final position data appear from below Table.

Radar location (Latitude, Longitude)	57° 04'28.45"N, 008°50'12.31"E
Aircraft altitude (above ground level)	150m
Antenna elevation (above ground level)	13m

Table 2 Detailed positions from site survey report.

All initial system design elements have now been taken into account. The final assessment of the OLC system performance will be evaluated and qualified as a part of the setting to work (STW) and site acceptance test (SAT) procedures carried out as final system approval.

2.1.3 System elements

2.1.3.1 Radar unit

The radar site consists of a SCANTER 5202 in single transceiver configuration, including MTI (Doppler based processing) and embedded tracker, combined with a 12-foot antenna with a fan beam elevation pattern.

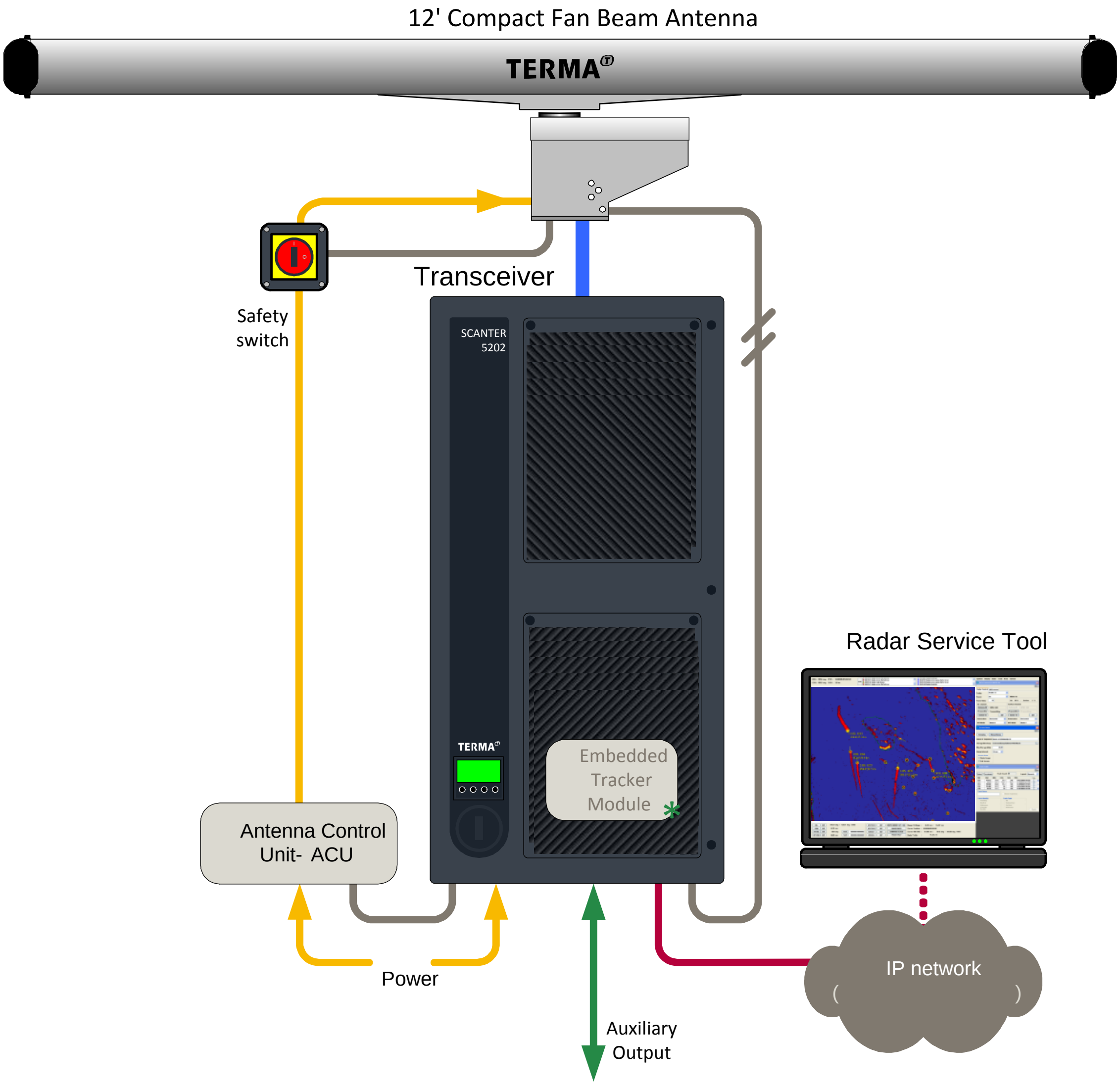


Figure 7 The radar configuration.

2.1.3.2 Light Control server

As described in section 2.1.3, the Radar Site, the Sub Station site and Light Tower Site (holding the interface the two light towers) interconnect via the customer communication infrastructure. The central LCS server is designed for unattended operation as such and provides an operator interface for monitoring purposes.

The operator interface can be accessed anywhere in the network, but in Østerild it is deployed at the Substation for convenience.

The radar system described above is also designed for unattended operation and likewise it has a remote monitoring operational interface, which can be accessed anywhere in the network. However, in Østerild it is deployed at the Substation for convenience.

2.1.3.3 Aviation light control interface

The aviation lights pre-installed in the WTG or in separate light masts are assumed to fulfil current applicable national regulatory for obstruction light equipment.

If more types of aviation lights are to be controlled by the radar system, we assume that the local light controller installed in the individual towers, control all types - alternatively that individual light controllers are installed for each aviation light type.

We also assume that either central or alternative distributed aviation light controllers connect to the wind farm IT infrastructure so that these can be central monitored and controlled from the LCS server.

If, for some reason, the pre-installed aviation light controllers do not provide any network connectivity, adaptation of current light controller equipment will have to be provided – alternatively, additional network enabling hardware must be added.

In the Østerild case, the present Obelux light controller gateway is updated with a TCP Modbus interface - providing the applicable connectivity to the central LCS equipment.

2.1.4 Overall functional description

This section seeks to describe the functional breakdown of the sub-components listed in earlier sections. The purpose is to provide the necessary documentation that the overall OLC solution will offer the adequate certainty, that the aviation obstruction lights are turned on under the correct circumstances, which comprises:

1. There is no connection from the central LCS server to the radar system

OR

2. The radar system is in an error state

OR

3. The radar system is not fully operational

OR

4. One or more tracks (representing targets) in one or more Surveillance Area Zones (forming the warning zone)

OR

5. One or more tracks (representing targets) have been lost in one or more Surveillance Area Zones (forming the warning zone) within a time period not exceeding the time-out period in the Surveillance Area Detection Zone in which the target has been lost

OR

6. There is no connection from the central LCS server to the existing Obelux Light Control interface (logging only)

OR

7. The Obelux Light Control interface is in an error/exception state. (logging only)

The functionality of the individual sub-systems has been described in the detailed site documentation. A full run-down of all exception associated with the radar system has been performed in the detailed safety analysis.

2.1.5 System validation and test

2.1.5.1 On-site Installation and setting to work

Installation and Setting to work has been performed by field engineers from Terma according to the approved procedures for OLC systems.

Figure 8 Radar OLC site in Østerild

2.1.5.2 Commissioning and SAT

The on-site integration of the SCANTER radar system with Tracker as well as fine-tuning of Radar site profiles has been conducted by Terma system engineers. This activity includes observation of clutter suppression and small target detection using test targets and/or targets of opportunity. Fine-tuning of the radar system is very site dependent (antenna height, weather conditions, etc.) and results in optimal settings (profiles) for best possible performance for small target detection.

After properly integration of the sensor, Terma system engineers have ensured the overall system performance by validating proper integration of the Obelux light control interface towards the LCS server.

All has been finalized by conducting the SAT procedure performed by system engineers from Terma according to the approved SAT procedures for OLC systems.

2.1.5.3 Performance SAT

In order to validate the complete OLC solution established in Østerild against all system requirements earlier described in section 2.1.2 site specific OLC specific test scenarios has been performed according to approved Performance SAT procedures.

This implies a dedicated controlled test target and any additional targets of opportunity. In order to fulfil the site-specific test scenarios a pre-defined flight plan with detailed waypoints in accordance with the desired trajectories has been prepared.

Flight plan for the Performance SAT can be seen on below figure:

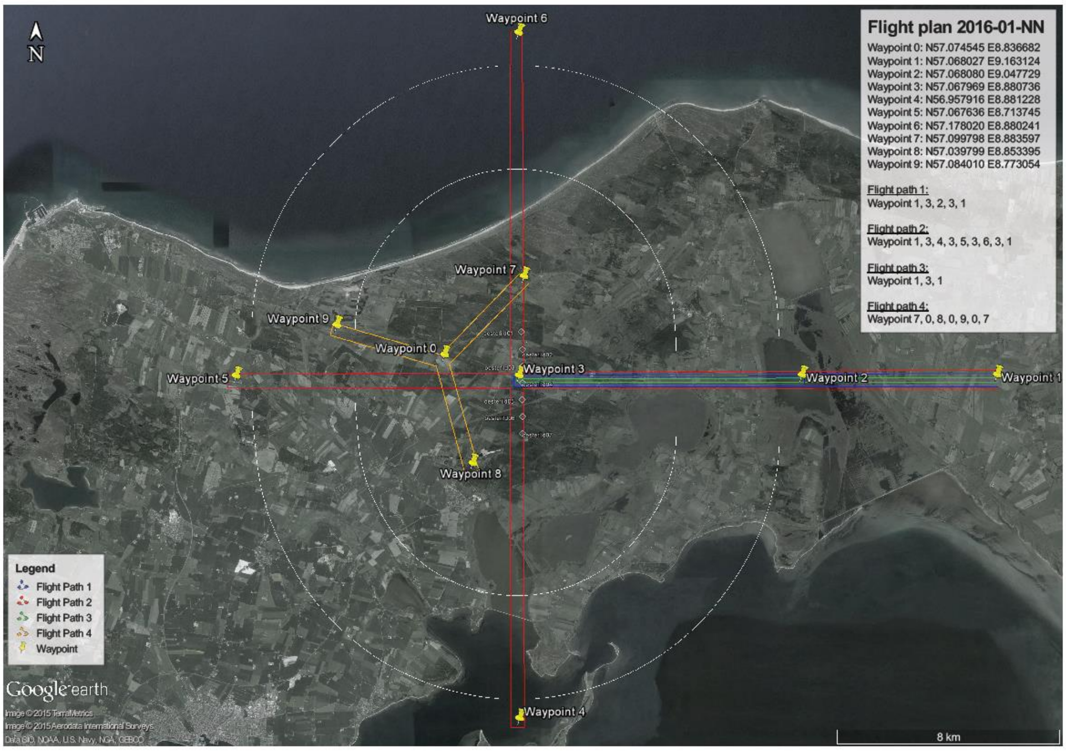


Figure 9 Performance SAT flight plan.

2.1.6 System operational approval

As mentioned in section 2.1.2 there exists no formal regulatory in Denmark concerning radar based OLC systems. The only regulatory available on the field is the Aviation Light regulatory, referred to as BL 3-11, which stipulates the rules about which aviation lights that must be installed on large obstacles such as wind turbines. Hence the only way to get an OLC system approved for operation is by applying for an exemption for the rules stipulated in BL 3-11. The national authority responsible hereto, is the Danish Transport, Construction and Housing Authority.

2.1.6.1 Exemption application package for the National Test Centre in Østerild

In general, there are no formal description how to apply for an exemption to BL 3-11. But in dialog with the Danish Transport, Construction and Housing Authority is has been agree to, that this can be done by preparing a detailed technical description and a safety case based on the principles in CAP670.

Also contained in the application must be all flight trials documenting the system performance described in the technical description.

Finally, also documentation for long term performance evaluation of the system, which must be provided to Danish Transport, Construction and Housing Authority at the end of the granted approval period.

Thus, the formal application drafted by the owner of the National Test Centre in Østerild (DTU Wind Energy) consists of the following documents.

- B1 - Technical Description A.pdf
- B2 - Safety Case A.pdf
- B3 - HAZOP study A.xlsx
- B4 - PSAT Test Report A.pdf
- B5 - PSAT Summary A.pdf
- B6 - Long term test evaluation 1A.pdf
- B7 – Mødereferat Trafikstyrelsen-DTU-Terma 14-12-2015

The listed documents come with a large number of supporting documents.

2.1.6.2 Approval process

After formal submittal of the application towards Danish Transport, Construction and Housing Authority, detailed assessment of the package was performed. Afterwards the complete application was send in 'hearing' at different stakeholders having any opinion on the matter; i.e. the national ANSP, the local airport in Thisted and also the MoD, represented by the Danish Defence Command in Karup.

2.1.7 Approval granting

Upon the finalization of the formal application process and after the proper hearing period the Danish Transport, Construction and Housing Authority approved a five-year operational test period for the National test Centre in Østerild. However, the authority put up several conditions for the approval and at the same time stipulation that these conditions must be fulfilled before the operational period may commence. In summary the installation at the National test Centre in Østerild went operational as per 1st of June 2017.

2.1.8 System operational learnings / additional testing

As the radar based OLC installation in Østerild is the first of its kind in Denmark is it very interesting to follow the system performance and stability quite close to monitor system performance and subsequently identify any possible enhancements over time.

One of the conditions for going into formal operation with the Østerild installation was that the system is only allowed to control the aviation light during night-time. That being defined from sunset to sunrise (as per agreed almanac). Hence apart from performing day to day monitoring of the installation it is also possible to conduct additional test and trials on the system during day time. Some of these test and trial will be described in the following.

2.1.8.1 Turbine/ radar co-existence

When position a OLC radar unit in the vicinity of a wind farm the turbines are not generally a problem for the radar. Two factors are interesting here. One being the blades from the turbines and the others being the towers of the turbines.

Regarding the first issue, test up to now have showed that despite normal perception of blades disturbing the radar, this is not a problem with today's high-resolution X-band radar capabilities combined with the quite advanced processing possible with current technology. That is also helped by the fact that the blades are not blocking micro waves completely regardless that the blades are turning or parked.

Concerning the second issue about the towers of the turbines, these are usually constructed of steel or concrete, which represent a more constantly micro wave blocking factor. At the installation in Østerild the Radar Unit has been placed approx. 2900m from the row of turbines installed there. All test and validation performed on site have not indicated that this matter represents a problem for the micro waves emitted and received. However, for generally understanding the matter, it is interesting to explore any distance to turbine tower constraints further.

Calculations and test results obtained up to now has showed that with a minimum distance from the radar to the nearest turbine (assuming average tower dimensions) of approx. 1000-1200m is sufficient to ensure adequate micro waves transmission. Below is calculation example of a micro waves transmission loss behind a turbine.

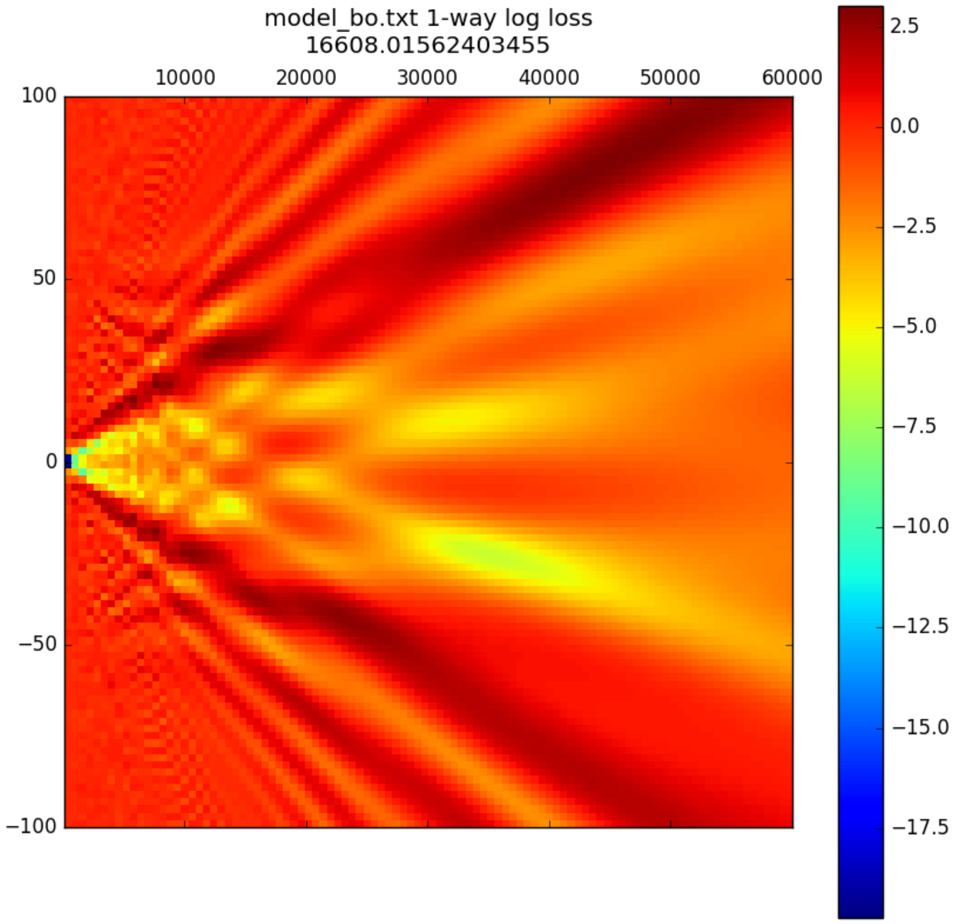


Figure 10 Micro waves transmission loss behind turbine.

2.1.8.2 Clutter

While pulse compression allows much better signal to noise ratio compared to a pulse radar, clutter is still reflections from actual targets, although unwanted targets. Advanced processing is used to remove unwanted clutter. If reflections from clutter becomes stronger than reflections from the actual targets it gets harder to distinguish between clutter and targets.

Clutter in a OLC environment generally originates from rain or surface reflections.

Adding the Moving Target Indicator (MTI), allows the radar to filter out stationary clutter to improve the target to clutter ratio.

Hence, our OLC solution provides a weighted combination of normal radar and doppler-based radar, which is forwarded for presentation and tracking.

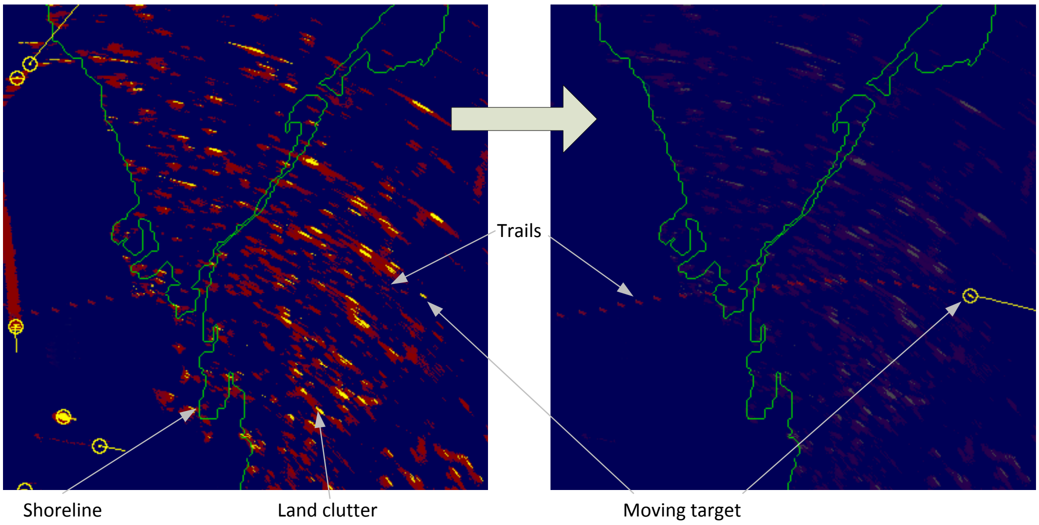


Figure 11 Normal radar video (left) and Doppler based processed video (right).

Various test and trials so far has indicated that, depending of the area of deployment, especially land clutter might represent a more severe problem that requires further attention in the normal radar channel. Currently this is done by manually masking out areas of concerns only in normal radar channel.

2.1.8.3 Weather resilience

In general radar signals are quite resilient against weather conditions, but a lot of factors must be considered when assessing the details. For one the frequency band (e.g. L, S, C, X, K_u) of the radar is playing a role as well as the polarization (radar waves can e.g. be horizontal, vertical or circular polarized). As we have experienced that more nations are moving away for the L and the S band, when it comes to radar based OLC solutions, we have chosen the X-band with horizontal polarisation as the most balanced solution. A full run down of all technical aspects of that topic falls outside the scope of this report.

Generally, wind is not a big concern when it comes to radar signals. Also, rain is generally not a problem for the OLC radar configuration we have selected. However, the combination of the two might at some specific point represent a challenge that needs taken into account. As can be seen from below figure that with some moderate high windspeed in combination with significant precipitation can result in radar detection of the incoming fronts of rain.

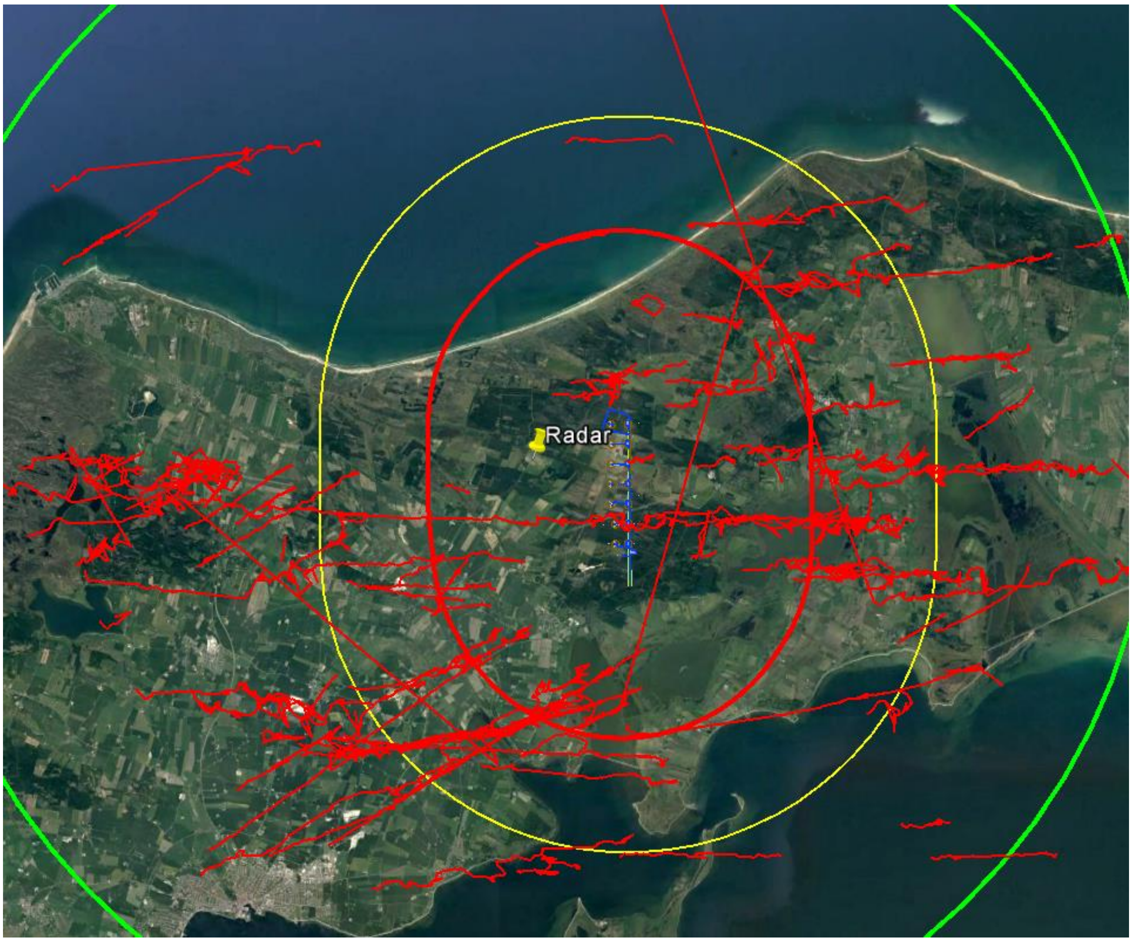


Figure 12 Rain front in combination with moderate wind speed in Østerild

Mitigation is for the time being, to optimize the configuration of the filtering of the initiated tacks in the system. See also below section.

Alternatively, it has also been substantiated that applying a target classifier functionality also can be a mitigation. See section 2.1.9.2.

2.1.8.4 False alarm rates - target filtering

Having ensured the most optimal settings of clutter suppressing and rain suppressing we have proceed to look at the more sustained actual track activity at the Østerild installation. In summary all track activities seem to be dependent of the season (weather) and quite dependent of the time of day.

In the figure below some samples are shown from the different season periods.

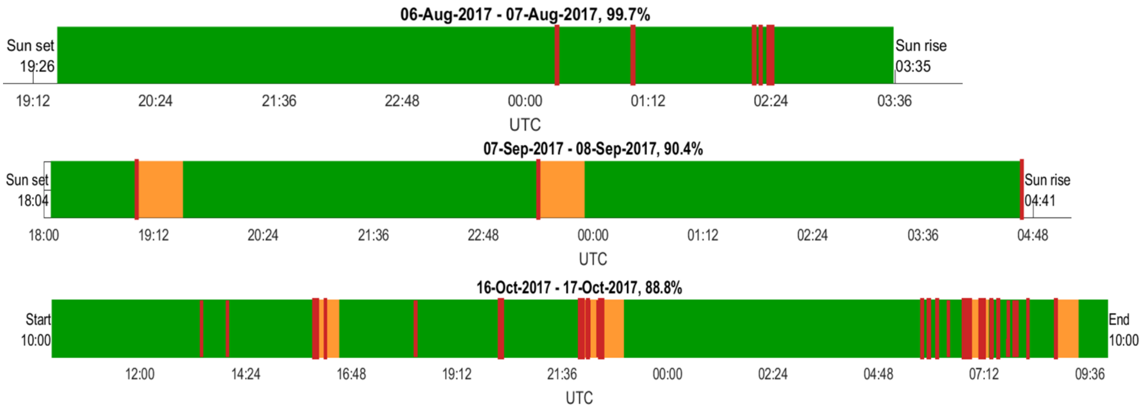


Figure 13 Track activities different days in Østerild

The red intervals represent the time where a detected air object is within the warning area causing the aviation lights to be activated. The orange areas represent the penalty time in case of a track being lost inside the warning zone. Currently that penalty time is set to 30 min. in accordance with the documentation approved by the authorities. Obviously, the time window for measuring the radar performance indicated in the figure headline is dependent of the almanac. Note that the measurements are only taking into account the activity from sunset to sunrise. Also note that a number of penalty periods can easily bring down daily performance.

Examining the daily track activity more in detail, reveals the fact that the activity derives from several causes:

- Genuine air objects (aircrafts)
- Non-genuine air objects (birds)
- Rain – mostly moving fronts
- Surface clutter

Clearly the genuine track activity is the only important one, when it comes to activation of the aviation lights, whereas all other track activities are categorized as false positives. Analysing the data some more points out the birds and the moving rain as the main as the main contributors.

If we start by looking at experienced bird activities, we can conclude the following

- Bird activity is quite focused around the areas, where they can find food (wet areas).
- Birds rises from their night residence (nests) quite early in the morning and returns in the evening.
- Birds or flock of birds are comparable in size (measured by the radar unit) to small genuine aircrafts (e.g. trikes)
- Birds (with possible tail wind) are able to travel with velocities (SoG) comparable to small genuine aircrafts.
- With the defined VFR airspace from 500ft to 2000ft birds will frequently enter and exit this airspace and thereby having high probability of triggering the penalty timeout.

Further investigations have brought us to the conclusion that the best way to mitigate this issue is to combine the track filtering doing a combination of the estimated track size and velocity, which also mitigates the above-mentioned rain clutter issue.

However, this is done conservatively to preserve aviation safety.

2.1.8.5 Long-time radar performance

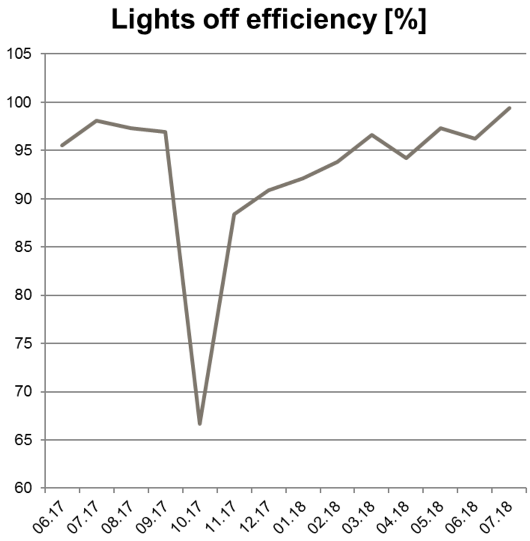
As mentioned the installation in Østerild has been in formal operation since June 2017.

In the sections above, we have discussed some of the factors influencing the overall performance of the OLC radar installation. Though, these are mainly focusing on the operation of the radar and as such not taking into account the state of the radar. That is to give a true picture of the overall long-time performance of the radar all anomalies or disturbances of the radar operation must be assessed.

Because the SCANTER radars are generally designed for unattended operation, a very comprehensive BITE functionality is built into the system providing real-time monitoring of all internal status of the radar, enabling that any BITE error of operative impact implies going into failsafe operation, as also mentioned in section 2.1.4.

In below figure complete operation status of the OLC radar at Østerild is shown.

Year	Month	Error [%] [a]	Uncertain [%] [b]	Detection Clear [%] [c]	Detection On [%] [d]
2017	6	0,0	4,0	95,5	0,5
2017	7	0,0	1,8	98,1	0,1
2017	8	0,0	2,4	97,3	0,3
2017	9	0,0	2,9	96,9	0,2
2017	10	16,7	14,7	66,7	1,9
2017	11	0,0	10,5	88,4	1,1
2017	12	0,0	8,5	90,9	0,7
2018	1	0,0	7,1	92,1	0,8
2018	2	0,0	5,8	93,8	0,4
2018	3	0,0	3,2	96,6	0,2
2018	4*	0,0	4,6	94,2	0,3
2018	5	0,0	2,3	97,3	0,5
2018	6	0,0	0,0	96,2	0,0
2018	7	0,0	0,5	99,4	0,1
Average		**1,9**	**4,9**	**93,1**	**0,5**



*23.04.18 to 30.04.18 excluded due to power failure at DTUs facilities.

[a] Error on the Radar system, [b] Lights on due to timeout / penalty timeout after losing the track, [c] Lights off, [d] Lights on

Figure 14 Long term efficiency figures in Østerild

The most interesting number is of course the average 'Detection Clear' level, which in Østerild yields 93.1% over the 14 months the measurements have been done, keeping in mind that only in this state the aviation lights can be turned off.

Another noticeable number is the 'Detection On' level, representing the level of activity that directly should turn the aviation light on. This number seems quite low but reveals the fact that genuine air activity is quite low in the area.

Also interesting are the numbers describing the 'Uncertain' state, equal to the penalty period referred to earlier. Given the fact that in the Østerild installation, the penalty period is in accordance with the exemption granted set to 30 minutes, which sums up to an overall contribution to the lights being activated on 4.,9%, given the local site air activity.

Also noticeable for the figure is the efficiency level from especially the November 2017 period, in which an internal radar error occurred and consequently influenced the efficiency. Root cause turned out to be a SW error, which afterwards was patched. Detection of the specific error took some time due to the fact that no formal system monitoring was established at that time as well as no service level agreement has been set in force.

2.1.8.6 Long-time overall system performance evaluation

From previous section it is clear that in order to maintain overall system performance, it is imperative to monitor performance on all subsystem constituting the complete system. This means that not only the radar performance need monitoring, but also the other subsystems (Light Control server and Aviation light control interface) described in section 2.1.3 must be considered. And not only on a unit functional level, but also containing the network and power connectivity to said subsystems.

Such monitoring functional capabilities is currently available on the Light Control Server unit residing in the middle of the network, connected on the one side to the OLC radar unit and on the other side to the Aviation light control interface. See below figure.

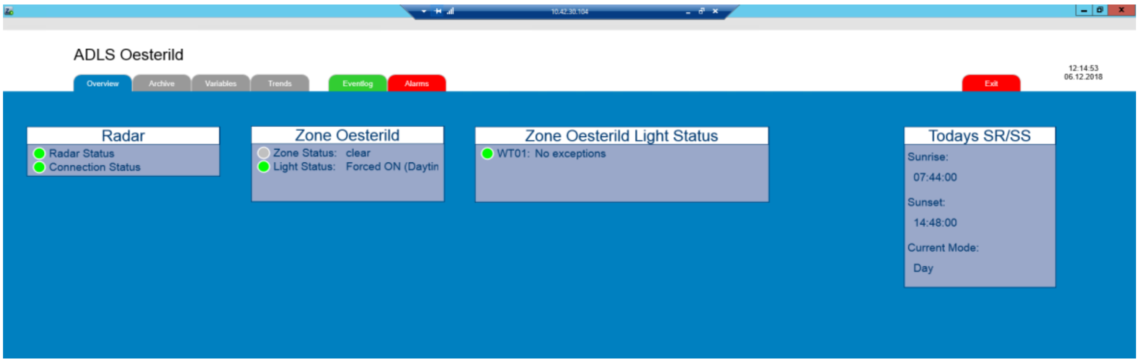


Figure 15 Status overview screenshot at Østerild site.

Likewise, the Light Control Server unit is responsible for logging and storing all events in the system, such as alarms, lights activation, track activity, error detections, etc., all for the purpose of being able to retrieve any desired incident information to at some point back in time.

2.1.8.7 Overall System monitoring

As described in previous section monitoring of all systems are available from the centralised functional capabilities on the Central Light Control Server. In the event that operation of the Østerild facility are attending the Status overview on a regular frequent basis this functionality would probably be sufficient. But normally and also at the Østerild site, daily operational personnel do not have the time or possibility to attend the status screen all the time. So consequently, - on top of the monitoring capability already described, it could be beneficial to have additional system monitoring capabilities located remote capturing any anomality and provide such information as notification to a predefined number of daily operational individuals in the form of e-mail or short message services (SMS).

Such functionality has now been included in a general service level agreement now in force at the Østerild OLC installation

Alternatively, if operation is to be conducted with already established operational centres, such centres can tap into the Central Light Control Server using various generic interfaces.

2.1.9 Additional improvements/learnings

As earlier mentioned the Østerild OLC installation has been on operation since June 2017 and as previous sections describes a number of test and trials have been conducted in order to learn more that can improve our OLC solution. Some of these will be described in the following.

2.1.9.1 System coverage

As indicated in Figure 6 the OLC radar in Østerild can easily fulfil the site-specific coverage requirement by having 10NM mile range. But in other sites and deployment we have identified the need for more coverage, for example in large wind farms or in wind farm location with more difficult terrain. In that context, we have introduced an OLC radar system with significant more coverage capability that enables us to extend the coverage to 14NM range, which apart from the immediate range enhancements gives considerably more manoeuvre room in the deployment of the OLC radar. Such extended OLC radar solutions have now also been commissioned in specific OLC projects giving the possibility to cover more wind farms with one radar.

2.1.9.2 Track classification

As can be captured from Figure 13 and Figure 14, the false alarm rates for the Østerild site (and others) are a balanced optimization of the track filter settings between the ability to detect genuine small air objects and not to detect unwanted non-genuine air objects, such as birds or moving rain fronts.

That has inspired us to introduce a track classification capability in the OLC radar providing the functionality to classify all acquired tracks. The Classifier is a newly developed product in the Terma product portfolio.

The Classifier is based on neural network principles and is thus a self-learning system built upon a machine-learning. This means that 'inside' the classifier an algorithm determines what category class a track belongs to, based on its input. See below figure.

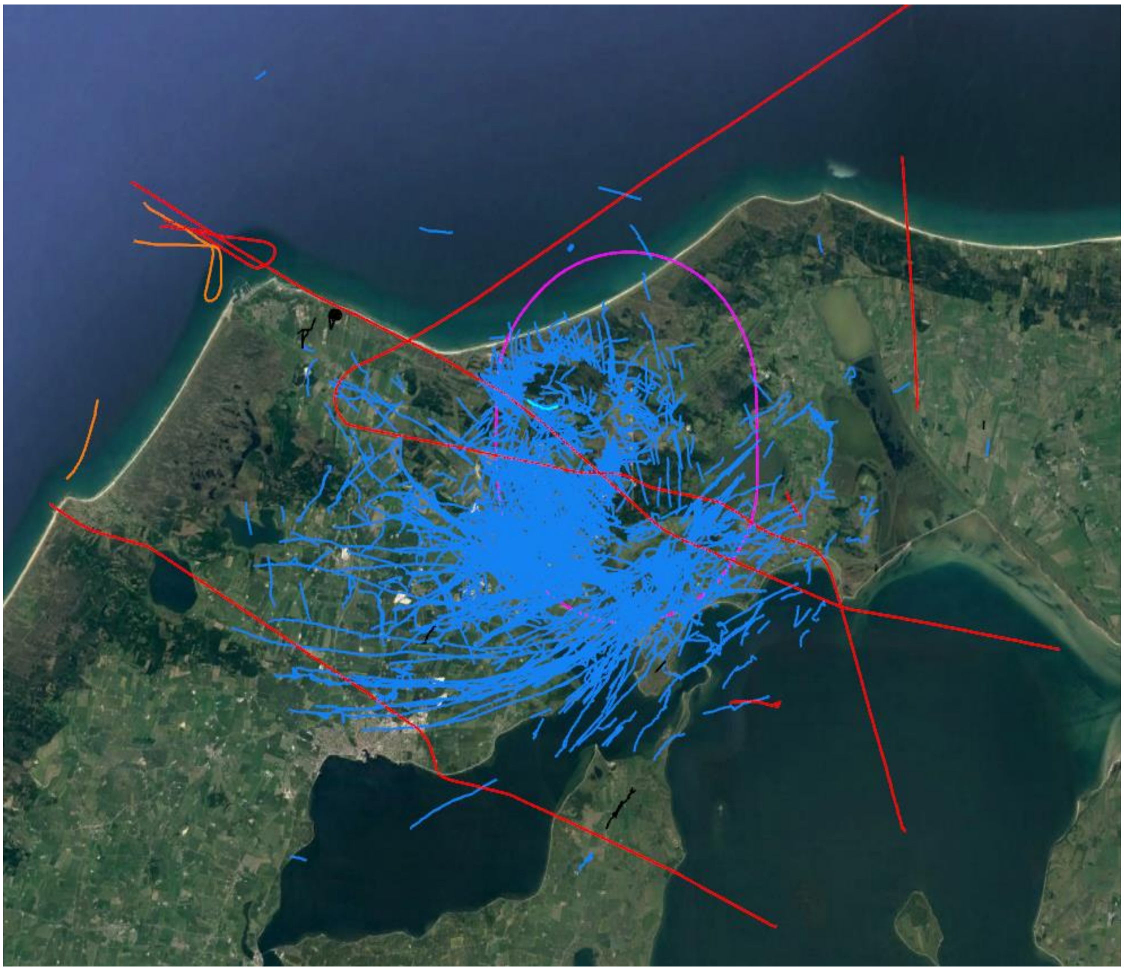


Figure 16 All tracks of the 15th November ET2 protocol with the Classifier enabled.

The figure shows the genuine air activity of aircrafts and helicopters represented by the red and orange trajectories, while bird activity is represented by the blue trajectories. The Classifier has been tested on tracks recorded in Østerild that has been analysed. Results have shown an average improvement of +10% detection clear for the month of November 2017.

2.1.9.3 Land Suppressor

As another specific outcome of all test and trials performed at the Østerild site we have identified the need for better tools to suppress the land clutter described in section 2.1.8.2, thereby introducing a dynamic land suppressor. On below pictures the blanking area in the normal radar channel are shown and the blanking process is quite time consuming and somewhat dependent on the environment present on the day of installation.

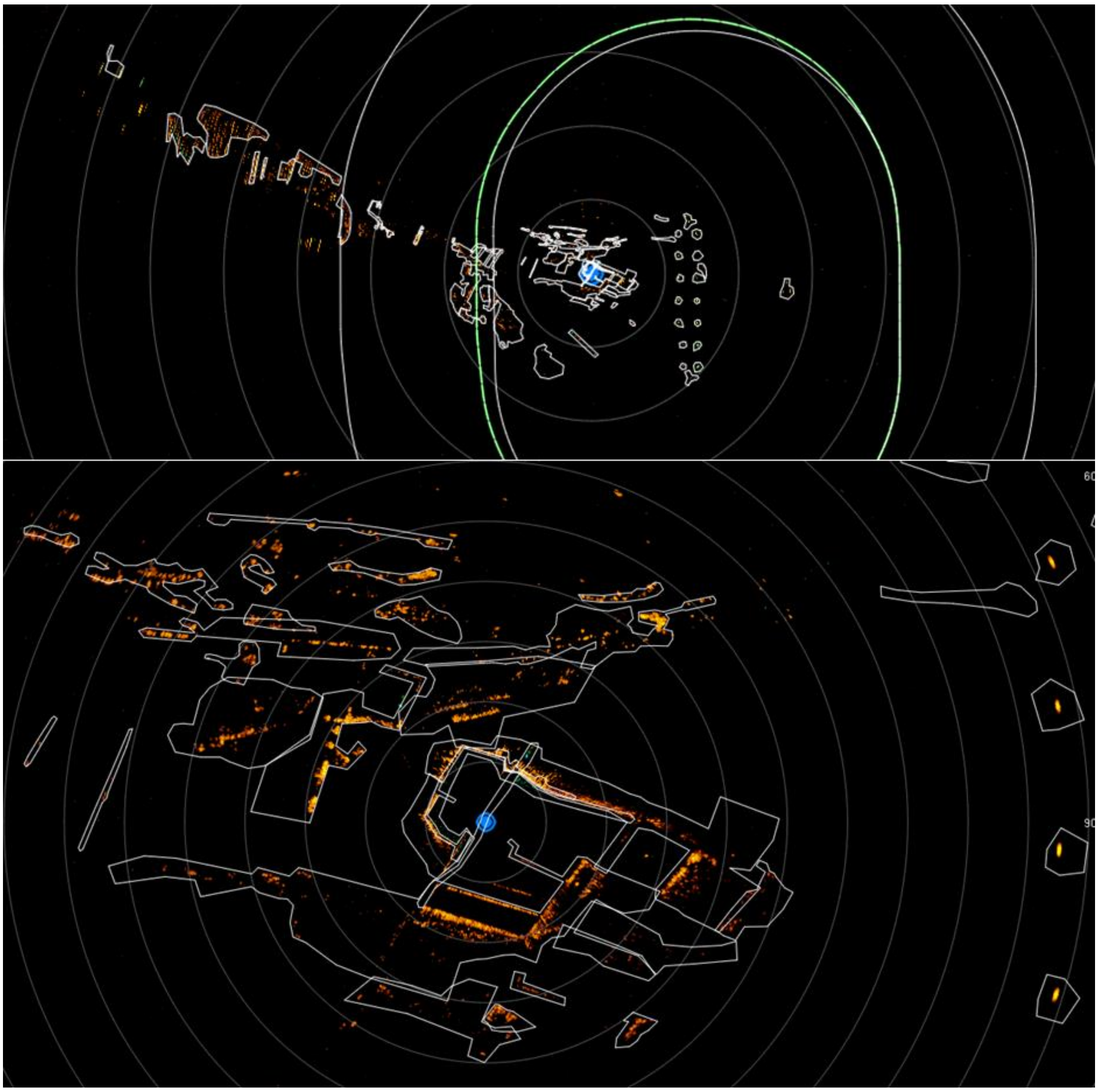


Figure 17 Blanking areas in the Østerild installation.

This being the incentive for us to introduce a more general land suppressor tool taking into account all land clutter issues such as buildings, structures, tree lines, power cables and other obstacles. The obvious advantages of the introduced land suppressor are that it by default covers the full radar area in an automated process and provides a dynamic estimation of all land clutter in the specific operational environment.

2.2 WP2: Derivation of the system requirements for a OLC solution

Reflecting upon the installation, stetting to work, commissioning, operation and various testing on the OLC installation in Østerild, it seems feasible to try to summarize the complete set of system requirements characterizing the current Østerild OLC installation. Though, also try to broaden the horizon a little by taking in other requirements/ideas identified from other domain experts/stakeholders in various fora.

2.2.1 General system requirements

- The OLC system must not dependent on aircraft equipment (non-transponder)
- Light intensity sensors might be allowed when lights are radar controlled
- Radar OLC is allowed between ECET and BCMT assuming the clock is synchronized with an astronomical clock.
- The equipment must comply with relevant CE requirement
- The system must detect all air vehicles in the defined airspace
- The equipment must perform self-diagnostic to verify system integrity
- The system must perform logging the operational status of the system
- The systems shall be enabled automatically when external power is applied
- The night obstruction light should turn off when there is not air vehicle in the monitored air volume, and the system integrity and detection performance is within expected design limits.
- When requirements for turning off obstruction lights are not met, the obstruction light has to be turned on immediately.
- No later than when the air vehicle enters the monitored air volume and when the air vehicle is within the air volume, the light shall be turned on.
- The monitored air volume is defined as +/- 15 deg. from obstruction light and with a radius of 5000m between 500ft and 2000ft in altitude.
- Site specific conditions has to be observed, i.e. mountains, trees, buildings.
- Obstruction light must comply with existing national regulatory.
- To be observed is all aircrafts that are flying under VFR/NVFR and VMC conditions in airspace class G.
- If the site within the military low-flying conditions, the detections systems has to observe a speed over ground up to 500 knots.
- All components of the systems shall to comply with the requirement for the site-specific climate conditions i.e. expected temperature, sunlight and humidity, icing, snow, water, salt mist.
- The detection unit must be designed so that adjustability, reproducibility
- and long-term stability are guaranteed.
- Maintenance concept in compliance with the manufacturer's maintenance guide-lines, which includes a system check at least every 6 months.
- Systems status for sensor unit, activation commands, status of communications system, status of control unit and status of lights must be stored for at least 90 days
- During the day (between BCMT and ECET) a photoelectric switch may be used. The obstruction light will be switched on if the ambient light falls below threshold of 50....150 lux.

2.2.2 Overall functional requirements

- The solutions must implement a solution to keep the obstruction lights off when there are no aircrafts in the vicinity of the windfarm, maintaining a high enough degree of aviation safety
- The system is to be considered as an unattended system
- One windfarm can be divided into multiple zones to decrease the amount of lights turned on in large windfarms.

- The solutions should be scalable - one sensor to many wind farms, many windfarms one sensor.
- The system must observe the effect of icing and snow not compromising the safety of the solution
- Systems individual components are required to perform self-diagnostic and any failure leads to 'turn light on' state.

2.2.3 System safety requirements

- The primary safety concept is always – if any malfunction – fall back to lights on.
- The solution should implement a reasonable high degree of quality to avoid false positives as birds etc.
- The solution must implement a basic real-time logging of subsystem status to support national safety requirements.
- To verify the operation of the system, each subsystem must be monitored for its fully operational status at any time – if any error – turn on the light.
- If an established track is lost with the warning the light must be turned on for predefined time period.
- A safety zone is defined including a distance and height from turbine where the lights must be turned on at the latest
- A detection zone with a sufficient range should be added to the safety design, to positive identify an aircraft and avoid false positive.
- The solution should implement a permanent echo to increase the safety of the solutions, including the operational status of the physical antenna

2.3 WP3: Generic recommendations/standardization for OLC systems

In all the work that has been performed from the initialization of this project and up to now; both within the project and in actual customer project trial and test a lot of findings and requirements have been identified. The radar based OLC solution described in current paper has been develop further and sold in several customer specific projects all in which specific requirements had to be fulfilled. To a great extend these have contributed to the further refinement of the solution.

In addition to that, many meetings, workshops, tradeshows, etc has contributed to the knowledgebase in our possession today.

2.3.1 Experiences from International rules and regulation on OLC

Due to the broad utilization of green energy and consequently also wind farms, many nations already have quite good ideas of how to implement OLC solutions, also referred to as BNK (GE), ADLS (US), ADS (CA, NL).

Currently only GE and US have a formal regulatory on radar based OLC systems. The OLC system described in this report has since the beginning of this projects been formal tested and qualified against these regulatory.

Commonly, most regulatory, both formal and draft are based on generic ICAO terms, using these to define the air volume to be covered. But in general, they are dealing with the problem in a similar approach but coming up with individual specifics when it comes to limits and values. It falls outside the purpose of the paper to do a complete run down and comparison of all available draft/formal regulatory.

Instead this paper uses the OLC requirements identified in section 2.2 and based on those try to set forth some recommendation for what to take into account in defining a draft Danish regulatory for OLC systems.

2.3.2 Considerations for Danish rules and regulation on OLC

As previous indicated the OLC system described in this report has been installed, tested and trailed in both customer specific projects, formal regulatory compliance test and other site-specific test, in which a lot of lessons learned have been acquired and this section aims at bringing as many of those to the table providing a quite practical approach to the task of drafting a Danish OLC regulatory. The following sections elaborates on selected main topics divided in a few overall categories.

2.3.2.1 System performance characteristics:

Warning Zone definition

One of the essential parameters of an OLC setup is to define the exact air volume on which boundary the aviation light must be activated. As described earlier most nations base their requirements on the minimum visibility requirement defined by ICAO, following the argument that if the minimum visibility requirements are met, the lights should also be visible on such distance. As shown in Table 1Table 1 Generic system parameters for ICAO.

visibility requirements are 5000m.

Alternative approaches to the problem has been experienced in different technical fora. Essentially the whole idea about activation the aviation lights is to provide adequate reaction time for the operator of the aircraft to avoid colliding with the obstacle in question. Consequently, defining the warning boundaries with respect to reaction seems feasible. Looking at the Canadian draft regulatory as an example, it states 30 seconds as the minimum reaction time. Seen from a technical point of view this makes sense as this implies that it will be the actual velocity of an aircraft determining the activation distance and not the worst-case figures. Downside of the time activation argument is that it firstly relies on the fact that the OLC sensor can determine a valid velocity vector and secondly that such requirement more complex to validate in the approval process.

Target time-out

It is generally recognized that no OLC sensor is ideal and as such there will be occurrences of identified track activity inside the warning area that might disappear for whatever reason. To mitigate this phenomenon usually a penalty time-out of the lights activation is applied in order for the lost track to be required or to vacate the warning area. Typical this time is set quite conservative (e.g. 30min) to be on the safe side preserving aviation safety. However, experience from actual operative installations, test and trials indicates that a more analytical approach to the problem is more feasible. So, in specific projects the timeout has recent been defined from worst-case calculation of track re-acquisition times also factoring in the OLC radars cone of silence from specific site measurements. This approach has reduced the track-lost penalty timeout to below 5 min.

Day / night operation

Looking at existing aviation light regulatory specifying the requirements for the type and variants of the aviation lights, it is obvious that lights requirements differs in the day-night scenario. Recommendation for the radar control is, that it should be allowed to work continuously, independent of that.

If only night operation is feasible, it should be considered whether any distinguishing between day and night should follow sunset/sunrise (almanac) or it should be follow the ambient light intensity or a combination thereof. Here the clear recommendation is to follow the ambient light intensity control (if present) as this is also controlling the different aviation light states (Day/Night/Twilight).

Real-time monitoring of system - failsafe operation

As OLC system is intended to operate unattended, it is evident that in order to preserve aviation safety measures to monitor system health seems imperative. This fact has also been quite important to all authorities, with whom the matter has been discussed. Hence, the overall requirement for all OLC system units should be that such must be capable of performing sufficient level of BITE and self-diagnostic to detect any degrading of unit performance and if so, take the proper counter-measures entering failsafe mode activating the lights. This also applies, if any external signals/connections to said system units is not behaving as intended.

Subsequently, in the case of any degradation implying failsafe mode, the wind farm owner should be aware and take mitigation action. To ensure that, it is recommended the OLC system should provide monitoring capabilities for such purpose. Furthermore, in the event that system is severely degraded (beyond failsafe), the wind farm owner is obliged to issue a NOTAM to the proper authorities.

Logging/reporting functionality

Recognizing that OLC system is intended for unattended operation, while also realizing that system anomalies might occur, it is recommended to require logging of all significant events (e.g. aircraft approach, aircraft enters/exits zone, lights on/off) and alarms (e.g. communication failure, radar failure, power failure) to provide a complete overview of the system performance. Such logging might be applicable in case of any incident handling/report and there for logfiles should be stored in the system for at least 90 days back in time.

2.3.2.2 Radar performance characteristics:

Non-cooperative detections system

In discussion with most of the authorities dealing with OLC regulatory the topic about cooperative versus non-cooperative detection system has come up at some point, but after thorough analysis of the issue they have all reached the conclusion to set the requirement for non-cooperative system. Main argument for this is that most nations do not have transponder as mandatory requirement for VFR aviation. Secondly, if this were to be mandatory, the cooperative system detection would still rely on the transponder installation in each aircraft is correctly installed and operative during flight and normal transponder installations are not redundant. Thirdly, transponders are not considered to provide sufficient safety level to be approved for OLC systems.

Target size and frequency band

When dealing with radar based OLC detection it is quite important to have a clear definition of the size of air object that must be detected. Normally this is referred to as Radar Cross Section (RCS). However, RCS is quite complicated to measure and in a practice an air object RCS strongly depends on the viewing angle. The scientific way to measure/test RCS is to use a metal sphere, which has a RCS independent of angle. However, such method is not easy to test/validate and again not representing any real aircraft. Again, the recommended practical approach is to define the desired target size by simply referring to a real aircraft representing the desired target size (e.g. Cessna 172).

Additionally, if dealing with RCS this might be dependent of the operational frequency of the OLC radar transceiver unit (e.g. L, S, C, X, K_u band), so if target size is desired, the frequency band should be defined.

Target altitudes and speed over ground

As discussed in the definition of the warning zone, it is also important to have a clear definition about the required detection altitudes in an OLC system, often referred to as the air volume. Again, ICAO flying rules seem to be the basis of the various nations requirements. ICAO VFR class G flying rules are defined from 500ft (above ground or water) up to 3500 ft. Though, most nations are limiting the high altitude down to 1000ft above the highest obstacle or 2000ft AGL. The rationale behind the upper boundary is defined by a maximum foreseeable descent rate.

Normal class G flying rules are allowing Speed over Ground (SoG) up to 250 knots.

If wind farm area is situated in military low flying zones, Speed over Ground (SoG) up to 500 knots should be considered.

Target detection over wind farm capability

Different approaches exist regarding OLC radar capabilities. Basically, the radar can be mounted on the turbine and operate a perimeter radar looking outwards from the wind farm, or the radar can be mounted on a mast separated from the wind farm looking in and over the wind farm.

Turbine mounted solutions does not generally have detection capability over the wind farm as line of sight is blocked by the tower. Normally, a turbine mounted solution would require at least 3-4 radars, possibly more depending on wind farm size.

Mast mounted solutions do generally have detection capability over the wind farm. Normally, a mast mounted solution would only require 1 radar, possibly 2 depending on wind farm size.

Clearly, the recommendation is to use mast mounted OLC radars having full surveillance capabilities over and around the whole wind farm, thereby also reducing the number of transmitting units concerning the radar frequency allocation.

Weather conditions

As the OLC solutions should operate unattended the equipment should be resilient against site-specific climate conditions such as expected temperature, sunlight, humidity, icing, snow, water, salt mist.

Real-time monitoring of static reference target

In obtaining the exemption from the Danish BL 3-11 aviation regulatory, a thorough system description, analysis and safety case documentation were prepared. One of the safety issues identified was how to deal with any non-foreseen degradation of the OLC radar, with the possible risk of an incoming aircraft not being detected. A mitigation to such degradation have been found by introducing real-time monitoring of some predefined static target at the specific site providing the trigger to enter failsafe mode in the event that the majority of such reference target are missing or weakly detected.

Efficiency level (false positives)

As also discussed in previous chapters, the experienced value of a proper installed and commissioned OLC system is to reduce the light pollution as much as possible, which is directly reflected in the efficiency level earlier described. Clearly, this is not a safety matter, though something to consider when assessing the feasibility of any OLC system installation.

2.3.2.3 Approval considerations:

In order to establish a deterministic way for wind farm owners to quantify the effort of obtaining operational approval of any wind farm with OLC requirement, it is suggested defining clear guidelines for the approval procedure – here-under requirements for:

- System documentation level
- Subsystem documentation level
- Safety case documentation level, if applicable
- Test procedure
- Flight trials
- Test Report

Additional it would represent value to any applicant to get an indication of the approval period that might be granted for a specific wind farm, of cause acknowledging that it’s not possible to predefine any period.

Furthermore, it might make sense also from an authority standpoint to have an opinion on how to ensure that long term performance is preserved. That might be in the form of suggested periodical inspection or that the applicant are required to provide a maintenance plan underpinning long term system performance.

2.4 WP4: Social impact

2.4.1 Introduction

WP4 dealt with the local perception of the obstruction lights at the Østerild test centre. The aim of WP4 was to explore the perception and impacts of the obstruction lights among local residents as well as the extent to which the operation of the radar-controlled obstruction markings is capable of alleviating impacts and changing people's perceptions of the obstruction lights. In order to assess potential changes this study was divided into two central parts, before and after the installation of the radar, which both consisted of a survey and interviews.

2.4.2 Methodology

With the aim of investigating citizens' perceptions of the obstruction lights at Østerild, this study was based on both quantitative and qualitative data collected during two periods, one before and one after the installation of the radar. The first period of data collection spanned May-December 2015 and the second period ran from October 2017 – May 2018. The following figure provides an overview of the research process.

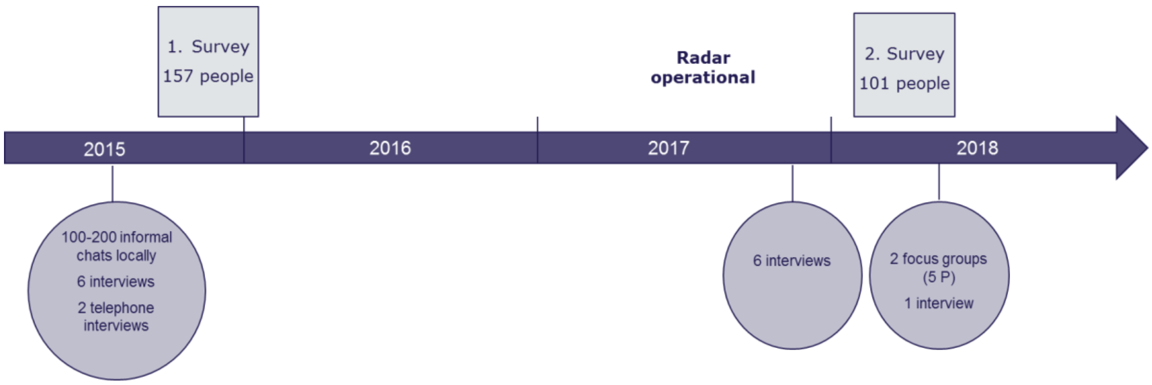


Figure 18 Data collected before the radar.

The data gathering in the first part comprised observations in the area, semi-structured interviews and an online survey. The number of survey respondents was 157, whilst in-depth interviews were conducted with seven people, and short interviews were carried out with more than 100 people. The qualitative data collection was conducted before the survey and served three purposes: a) to raise awareness of our study b) to gather a first impression of how people relate to the obstruction lights, and c) to acquire knowledge about the wording people use when referring to the obstruction lights. All this information was used to prepare for and inform the structure, content and wording of the subsequent online survey.

At first, a team of 4 researchers had 100-200 informal chats in the local area around the test centre between 18-19 June 2015 in order to gain initial insights in how people perceive and relate to the obstruction lights. This was mainly done in front of two local schools where people gathered at poll stations for the national election, but also in local shops. In addition, six pre-arranged and semi-structured interviews with residents in the vicinity of the test centre were held in order to obtain more detail on how people feel affected and annoyed by the lights, their main concerns and their potential coping strategies. Interviewees were selected based on relevant written comments to the public consultation phase of the planning of the test site as well as based on their residence close to the test site. Semi-structured interviews allowed for a discussion of predefined topics, while leaving enough room for addressing unforeseen issues that interviewees deemed relevant. Thus, the content of the interviews was based on findings in the existing literature regarding stress and annoyance related to the perception of light pollution and also related to desk-based research regarding the test site and surrounding area, and revolved around the top-down planning process, and the public consultation responses to the EIA. The pre-survey fieldwork also included observations in the local area in order to identify how topography and local geographical conditions influence the visibility of the aviation obstruction lights in the area around the test centre. Finally, the fieldwork was used to distribute leaflets about the upcoming survey in local gathering points and mailboxes of surrounding houses.

The main element of the study, before the radar had been installed, included an online questionnaire. The questionnaire was developed based on research interests and preliminary findings from the interviews. Inspiration was also drawn from a previous study conducted in Germany by Dr Johannes Pohl and colleagues from the University Halle-Wittenberg that dealt with the perception of different types of obstruction markings for wind turbines. Johannes Pohl also provided feedback on the questionnaire. The survey focused on understanding people's perceptions of the lights, i.e. how they perceive the obstruction lights and to what extent they feel annoyed by the lights under various conditions. Similar to Pohl's study, the survey attempted to distinguish the actual perceived annoyance from general attitudes and values towards the test centre, distinguish the impacts related to obstruction lights from visual impacts of the wind farm and light masts and other impacts, and examine how and when people feel annoyed. In total the questionnaire consisted of 30 questions, ranging from people's perception of the local area to their experiences of the obstruction lights, coping strategies and to related stress effects and well-being.

The survey was structured in a way that it only gradually delved into the issue of obstruction lights in order to minimize bias. The last part related to people's background and contact information. The latter information was provided by respondents on a voluntary basis, as it would not allow for maintaining anonymity of the data but facilitated a greater comparability with the second survey. The questionnaire was transferred into an online survey by *Rambøll* using the software *survey-exact* and was disseminated from September until December 2015. This period was chosen due to the longer darkness between dusk and dawn, so that respondents could relate to the lights and their effects more directly. The recruitment of respondents included leaflets, a public meeting, a Facebook site, posters in local shops, and newspaper articles. A Facebook site and group (215 followers in 2015 / 275 followers in Nov 2018) were created to recruit respondents and to keep local people informed about the study. Four articles were published in the local newspaper in cooperation with a journalist (Thisted Dagblad). All activities served to circulate the URL of the online questionnaire. Eventually, the offer of prizes of wines and chocolates was aimed at incentivizing more people to participate.

The total number of respondents was 157, whereas 149 completed the survey fully and 8 respondents refrained from answering a few questions. However, this number is not considered as a representative sample of the local population. Due to the number of respondents and the non-probability sample, regression analyses did not produce significant results, and the analysis is therefore only based on descriptive statistics.

A public meeting held in Østerild in December 2015 was used to disseminate preliminary results of the survey among interested local residents. Approximately 50 people attended this meeting at Østerild Inn. More details about the methodology used in the first part of the study can be found in the article in the appendix. Methodological challenges of the first part of the study were related to the translation of survey questions from German (due to Pohl's study) to English and then Danish while keeping semantic nuances, and the fact that a few interviews were conducted in English, which may have likewise caused a lack of nuances in the interviews.

2.4.3 Data collected after the radar

The second part of the study followed a similar methodology including interviews and a survey. At first, six semi-structured interviews had been conducted with local residents before the second survey was developed, whereas four interviewees were identical with the ones from the first round of interviews. The interviews focussed on the perception and experience of change after the installation of the radar in order to inform the development of questions for the second questionnaire. However, similar to the first round of interviews, in which one central issue related to top-down planning process of the test centre, the information gathered during the second round of interviews was likewise blurred with debates about the expansion of the test centre. Based on the interviews and the first survey, the researcher team discussed the scope and focus of the second survey, which resulted in the development of the questions for the second survey. In line with the previous questions, the second questionnaire put more emphasis on the perceived change after the installation of the radar. This questionnaire consisted of 24 questions in total, while 21 questions were related to the perception of change due to radar-controlled obstruction lights as well as alterations in coping strategies and annoyance, 2 questions focused on the expansion of the test centre and one on personal information. Questions about psychological stress effects and well-being were not considered in the second survey, as these were not deemed relevant due to a lack of completeness and clarity in the first survey. Instead, an important question related to whether respondents had participated in the first survey 2.5 years earlier in order to ensure the comparability of certain items. The total number of respondents was 101, whereas 52 indicated that they took part in both surveys. However, a challenge emerged due to regulatory imposition of red obstruction lights that were installed between the two parts of the study and that necessitated clear differentiation in the questionnaire to avoid confusion for the participants. The recruitment process of participants followed the same pattern as the first survey and made use of leaflets, posters, the Facebook account and a newspaper article. Again, the survey was transferred into an online version by *Rambøll* and was put online between February and April 2018.

The data analysis made use of three statistical analytical methods: Descriptive analyses of frequencies and distributions, the Wilcoxon signed rank test, and multiple regression analysis. Descriptive statistics were used in all analyses but specially to create an overview of the themes in the 1st survey. The Wilcoxon signed rank test was used to assess the social impacts from the implementation of the radar. The Wilcoxon signed rank test is a non-parametric test that compares medians of variables at the two points in time; pre-radar and post-radar. In addition, the effect size is calculated to assess which impacts from the obstruction lights have changed the most due to the implementation of the radar. Finally, the multiple regression analysis was used for analysing the factors that influence the perceived annoyance in the local community, as it allows for the assessment of which factors have the strongest influence on the annoyance level. This was done in order to understand *why* implementing the radar-control had a positive effect on annoyance.

In contrast to the first part of the study, the survey was followed by two small focus groups and another interview carried out in May 2018, which served as a further and more detailed elaboration on the experiences of landscape change due to wind turbine test centre in general and the obstruction lights and radar in particular. The selection of these participants was based on previous contacts and people, who completed the first survey. Together with the interviews from the first round, in total 16 semi-structured interviews (including one telephone interview and two focus groups) were conducted between 2015 and 2018. Finally, a public meeting was held at the visitor centre of the test centre in October 2018, in which key findings of the entire study were presented. The meeting was attended by 15 citizens.

2.4.4 Findings from the pre-survey interviews

When the interviews were carried out in June 2015, the lights masts had been in place for almost three years. While the general attitudes towards the obstruction lights had been mostly described by the phrases 'I can't see them, and I don't care' or 'I got used to it', some interviewees described certain physical and geographical conditions, where they felt most bothered by the obstruction lights. A few others referred to other people, such as friends and neighbours, who were regarded as being more affected than themselves. Several interviewees also referred to a time shortly after the lights had been installed, where there was a technical failure causing an extraordinary exposure to a high intensity of the lighting system. The eradication of this failure and adjustment of light exposure resulted in people referring to 'getting used to it now', because they had experienced a worse situation before. However, the informal chats also clearly hinted at the significance of the micro-geography in influencing the visibility of the lights and thus the annoyance of certain people.

Several broader themes emerged from the pre-survey interviews, including place identity and a loss of darkness, behavioural changes due to the light exposure, early failures in the light system and the planning process of the test center. The early interviews before the installation of the radar showed how the selected local people felt extremely affected by the lights. Interviewees reported on how they could not sleep properly, did not have to turn on the lights during the night and were afraid of unknown health effects.

The first round of interviews in 2015 also showed that people's annoyance of the obstruction lights could not be clearly detached from both their perception of the landscape and nature as well as the planning process. First, the test center was situated in a rural area that is characterized by tranquillity, silence and darkness. The darkness was described as a unique feature that could not be found elsewhere in Denmark. Thus, changes of sensory and aesthetic experiences did not only alter the meanings ascribed to places depending on the underlying individual and symbolic meanings associated with these places, but also their everyday behaviour. Some interviewees described how they felt like having to restrict themselves in their activities when 'turning their back to the lights' and changing movement patterns and walking routes while spending time outdoors. Hence, the obstruction lights were considered to contribute to the loss of this unique landscape and nature, which points to the perceived value of experiencing darkness and lightless places in a world, which is becoming increasingly over-illuminated. In emphasizing that, people referred to differences between urban and rural areas. The impacts of obstruction lights had already emerged as an issue during the consultation process. Even though the EIA briefly acknowledged impacts of the lights on the vicinity, it did not provide a thorough assessment of these impacts.

Second, the annoyance of people by the obstruction was closely related to the planning process and locational decision-making of the test center, in which local people and authorities did not have a say. The findings also indicate that the emotional constitution of perceived annoyance was not only grounded in the actual source of nuisance, but was also entangled in related issues, in our case the perception of disempowerment in an unfair planning process, which for some people had even made them question their democratic rights in Denmark. So, the flashing lights were also considered, by some local residents, as a constant reminder of the faulty top-down planning process, which had provided very little leeway for addressing people's concerns. The internalization of planning-related iniquities may also hint at why coping strategies aimed at mitigating the physical impacts of the obstruction lights were described as not very effective in allaying people's affectedness.

A more detailed discussion about specific themes will be provided in the findings of the second part of the study.

2.4.5 *Results from 1st survey*

This section summarizes key findings from the first online survey on before the radar was installed, the purpose of the obstruction lights, perceived annoyance under different conditions, the relation between annoyance and sense of place, people's behavioural changes and coping strategies.

First, the majority of responds finds that the obstruction lights should only be switched on when it is necessary once a plane is nearby. This indicates a desire for a solution that allows for a flexible use of the obstruction lights.

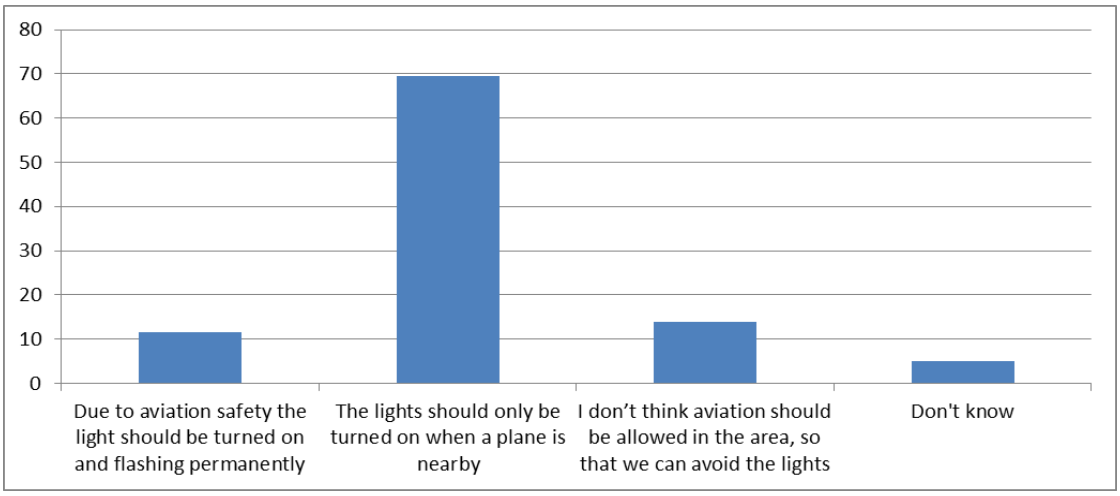


Figure 19 Preferences towards the use of obstruction lights.

Second, we consider the perception of the lights under different conditions. The perceived annoyance from obstruction lights differed across season and time of the day and depended on the weather conditions as well as on citizens' activities. Unsurprisingly, the annoyance by the obstruction lights was less severe during daylight than during darkness, with the highest degree during dusk, as people stated that they were very annoyed (34%) or pretty much annoyed (18%) (see Figure 20). The influence of weather conditions is also obvious in the data showing a higher annoyance when the sky is clear. However, some citizens stated in the interviews that the lights were particularly annoying during misty and foggy weather, because the fog is meant to scatter the flashing lights. The interview data also indicates that the micro-geographical setting around individual houses determine people's perceived annoyance. The data showed that the extent to which people noticed the lights depended on factors such as whether there are trees outside the window to offer shading from the lights, whether or not the house faces the test site, whether the house is close to water, which will lead to reflection in the water, and whether or not the bedroom windows are facing the test site. Thus, the distance to the test centre and the light masts does not seem to be a determining factor for perceived annoyance, as some people, living closer to the test center, may be shielded by the plantation forest.

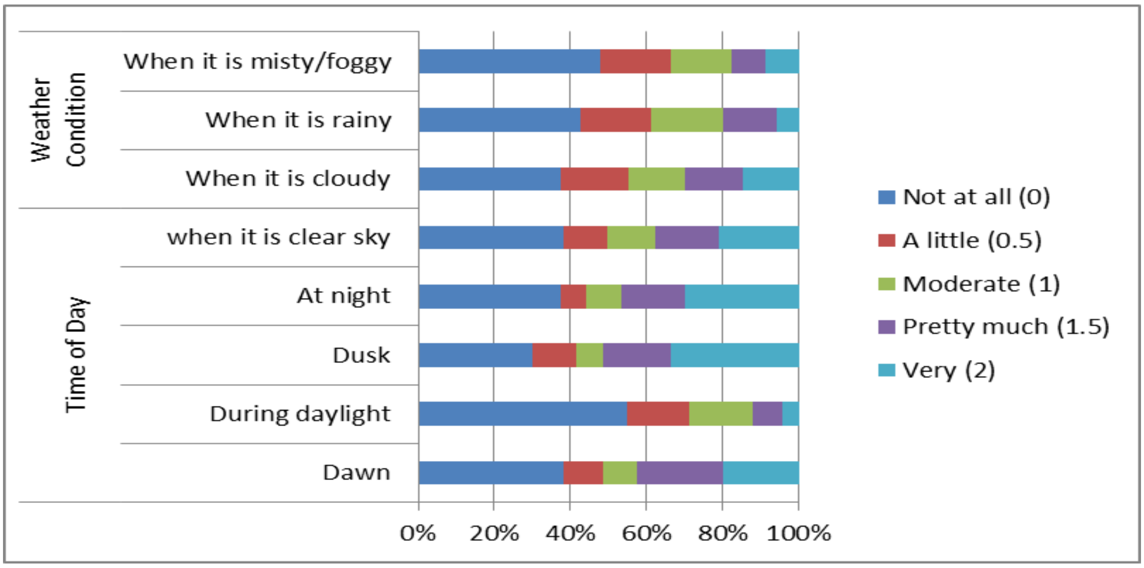


Figure 20 Extent to which people feel annoyed by the obstruction lights at different conditions.

Moreover, yet not surprisingly the degree of annoyance is related to the frequency of perceived annoyance, whereas people who repeatedly notice the lights stated that they are very much annoyed by them, especially during night and twilight (Table 3). Likewise, a notable amount of the moderately annoyed people rarely noticed the lights.

		Annoyance by obstruction lights from Test Centre over the day							
		Very much and a lot				Not at all			
Frequency of disturbance		night	dusk	dawn	day	night	dusk	dawn	day
	Once a week & less (26)	2	2	2	0	21	20	22	24
	Almost daily (39)	6	7	4	1	24	16	26	34
	1-5x a day (35)	22	26	15	6	5	3	4	12
	>5x a day (50)	43	46	40	12	2	1	1	9

Table 3 Relationship between frequency of disturbance (winter) and annoyance by obstruction

Third, there is also a strong relationship between the sense of place and landscape, i.e. certain qualities attached to the places and the surrounding environment, and the perception of the obstruction lights. According to Table 4, there is a relation between people's annoyance by the lights and the perceived decline in the qualities attached to the local area and landscape, i.e. more annoyed people also perceive more negatives changes to the landscape due to the lights. There is also an indication of a correlation between the frequency of disturbance by the lights and the perceived decline of landscape qualities, highlighting the significance of light exposure as a critical factor (Table 5). Similarly, since darkness was mentioned as a particularly meaningful feature of the area, it is not surprising that a negative perception of darkness and dark sky increases with the frequency of noticing and being disturbed by the lights (Table 6). People, who felt that their experience of darkness got worse, were also the ones who were annoyed by the lights at night and during twilight. In terms of attachment to the area, the data showed that those who felt that their attachment had become weaker were generally very annoyed by the obstruction lights, whereas those who were not, or those who were only a little annoyed, mostly stated that they had not perceived any change in their attachment to the area. In a nutshell, the more people notice and feel annoyed by the lights, the more they sense their living environment has changed negatively, or the other way around.

		Annoyance by obstruction lights		
		Not at all or a little	Moderate	Pretty much or very much
Landscape qualities	Negative change (81)	6%	10%	36%
	No change (51)	31%	2%	3%
	Positive change (19)	10%	1%	2%
Nature qualities	Negative change (69)	5%	8%	31%
	No change (63)	31%	3%	6%
	Positive change (25)	10%	1%	4%
Quietness qualities	Negative change (54)	4%	4%	27%
	No change (100)	41%	8%	15%
	Positive change (3)	2%	0%	0%
Change in attachment to the area	Weaker attachment (13)	1%	1%	16%
	No change (67)	37%	10%	24%
	Stronger attachment (10)	8%	1%	1%

Table 4 Relationship between perceived changes in the quality of the area, attachment to the area and perceived annoyance by presence of obstruction lights as an average over the course of the day. (adapted from Rudolph et al. 2017).

		Perceived change of quality of area								
		Scenery / landscape			Nature			Quietness		
		Very/little negative	No change	Very / little positive	Very / little negative	No change	Very / little positive	Very / little negative	No change	Very / little positive
Frequency of disturbance	Once a week & less (26)	5	15	6	4	16	6	3	22	1
	Almost daily (39)	9	25	5	10	24	5	6	31	2
	1-5x a day (35)	26	6	3	22	7	6	18	17	0
	>5x a day (50)	41	5	4	33	10	7	27	23	0

Table 5 Relationship between frequency of disturbance by obstruction lights and perceived changes in the quality of the area.

		Frequency of notice of lights / disturbance (winter)		
		Almost daily	1-5x a day	>5x a day
Perception of darkness	No change (51)	26	3	0
	Worse (27)	6	10	9
	Much worse (67)	5	22	39

Table 6 Relationship between change in perception of darkness and frequency of disturbance by obstruction lights.

Fourth, although annoyance levels are generally influenced by the time of day, weather conditions, micro-geography and loss of darkness and sense of place, the survey results also showed that local residents were personally affected by the lights in different ways, depending on the activity they are engaged in Figure 21. Whilst people were not noticing the lights much when working, they tended to be much more prone to disturbance when engaged in leisure activities, such as watching TV, walks in the nature, star gazing or bird-watching.

While this difference may be explained by e.g. the time of the day for different activities, the interviewees explicitly referred to certain values, when explaining the impact on leisure activities.

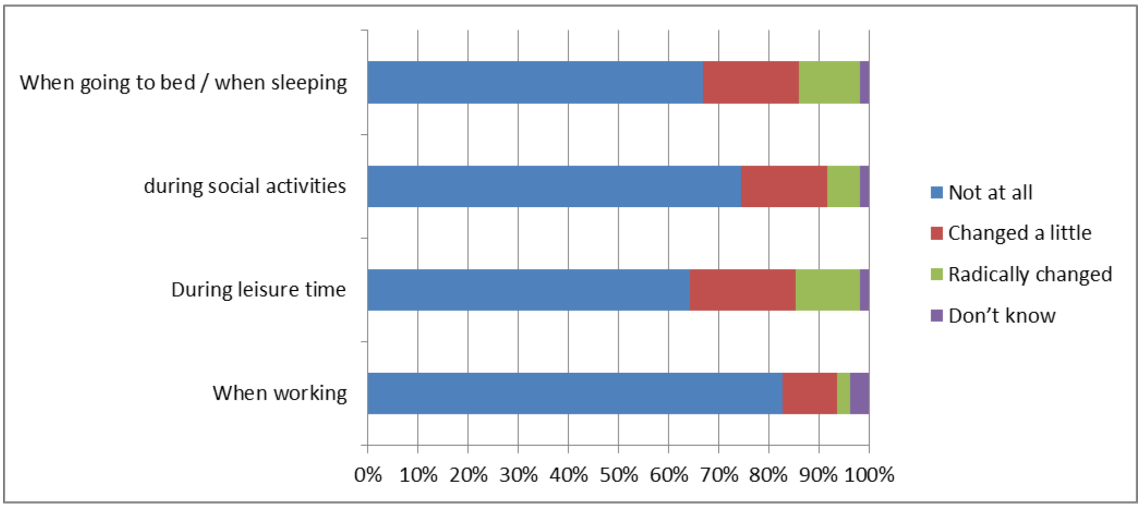


Figure 21 Adaption of behaviour during certain activities due to the lights.

Survey respondents have adopted different strategies in order to cope with the effects from the flashing lights. When feeling annoyed, most people have adopted less radical measures to alleviate the impacts of the lights in their daily lives, such as using blinds, moving around furniture inside and outside the house, changing walking paths and planting trees to shade their houses from the light (see Figure 22). There was one case of a resident moving away from the area due to the impacts of the test centre and the changes it caused. While the majority of people referred to most measures as not necessary, the data demonstrates that many people applied one or another strategy to cope with the effects of the flashing lights on their everyday lives. However, the data also indicated that coping strategies have only had a limited effect on alleviating the levels of perceived annoyance, whereas coping strategies with the relatively largest influence are physical changes, such as adjusting outdoor activities, installing blinds, shielding lights with infrastructures and plants or the rearrangement of furniture. Other activities, such as complaints, protest groups or the use of pharmaceuticals, were not deemed as efficient in coping with the obstruction light and their impacts.

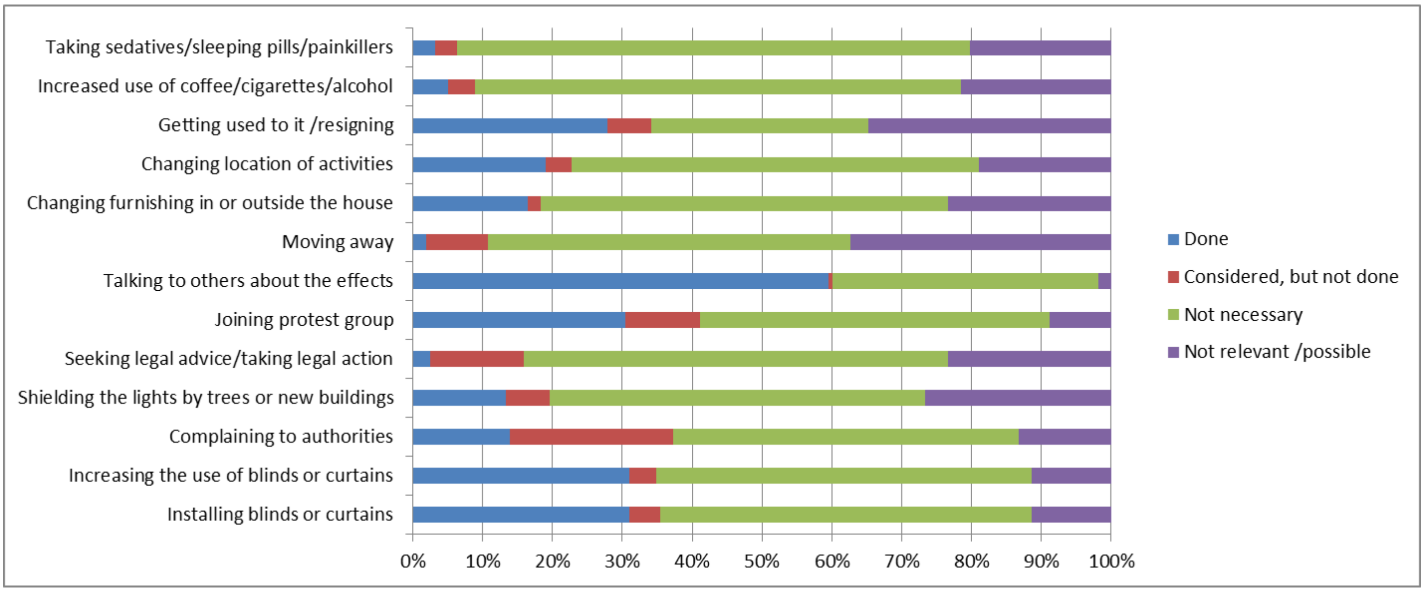


Figure 22 Frequency of coping strategies (adapted from Rudolph et al. 2017)

More details about these issues can be found in the Annex A.

2.4.6 Results from the 2nd survey

Following the presentation of the perceived annoyance under different conditions, the relation between annoyance and sense of place and people's coping strategies caused by the lights from 2012-2015, this section presents the changes to the social impacts from the lights on the local community which was brought about by the implementation of the radar-control system from June 2017. The post-radar analysis focussed on the following measures for assessing the social impacts of the radar-control system:

- Awareness of the lights
- Attitudes towards the Østerild test centre
- Health and well-being
- Sense of place
- Annoyance with the lights

2.4.7 Results

The results show that the local residents´ awareness of the lights is generally reduced in the period following the installation of the radar (see Figure 23), and this is according the respondents, a direct effect of the installed radar-system. Thus, when asked whether the installation of the radar-controlled light-system has caused them to notice the lights more or less, the respondents report that they notice the white obstruction lights less or a lot less at all times of day and year.

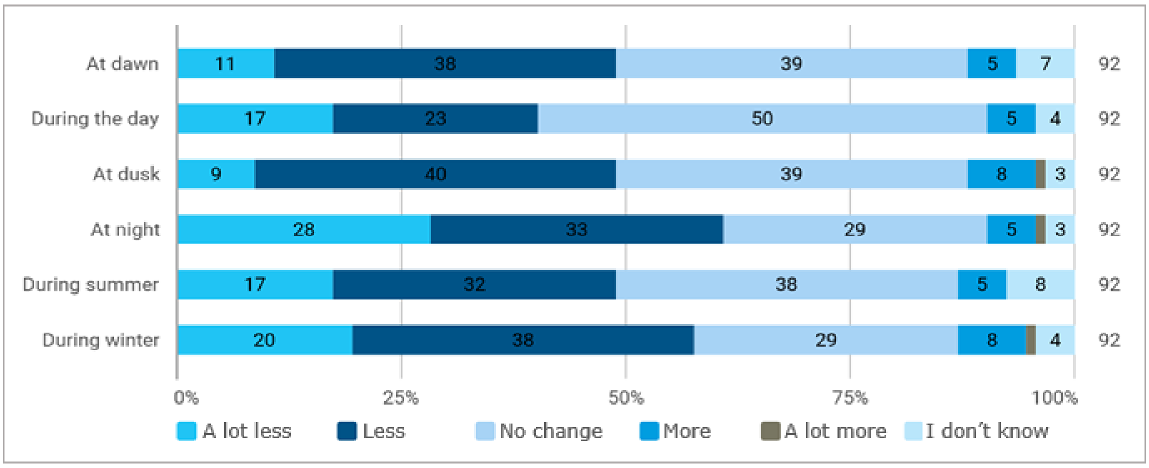


Figure 23 Answers to the question: Did the installation of the radar-controlled light-system (since July 2017) cause you to notice the white lights more or less under the following conditions?

The change is most significant during winter and at night, where respectively 58 pct. and 61 pct. of the respondents' report that they have noticed the white obstruction lights less or a lot less. This is perhaps not surprising given that these are the periods where the impacts from the white obstruction lights have been strongest and that the radar only controls the lights from sunset to sunrise. Hence, the effects of the radar will be largest there.

Furthermore, the implementation of the radar has had a positive effect the residents´ attitudes towards the test centre in general. Between 42 pct. and 47 pct. of the respondents thus report to have a more positive or much more positive attitude towards the test centre as a result of implementing the radar. At the time of questioning, the radar-system was running with some malfunctions which affected attitudes towards the test centre negatively but even so, local residents had generally become more positive towards the test centre.

Finally, the effects from the installation of the radar on the general well-being and health measured by the general health and well-being, happiness, stress and general performance of the local residents have been rather limited, and the results must be considered non-conclusive.

The 2nd survey did not investigate the self-reported changes to the residents´ annoyance level. Therefore, a comparison between the answers from the 1st survey and 2nd survey was made using the Wilcoxon signed rank test. The test provides an opportunity to generalize the results beyond the sample. Table 7 describes the factors for which there is found a statistically significant change between the 1st survey and the 2nd survey. The test was performed on the respondents who answered both the 1st and the 2nd survey.

		Median		Significance (p)	Effect size (r)
		Pre-radar	Post-radar		
General annoyance	To what extent do you feel bothered by the WHITE aircraft obstruction lights from test centre Østerild in the following conditions? (1=Not at all, 5=Very)				
	… When it is dark outside in the evening	4	3	0,000	-0,48
	… At night	4	3	0,014	-0,34
	… When it is cloudy	2,5	2	0,022	-0,32
Daily annoyance	Do the white obstruction lights bother you in your daily activities? (1=Not at all, 3= To a larger degree)				
	… When I am taking a walk	2	2	0,046	-0,28
	… When I am relaxing	2	2	0,015	-0,34
	… When I am reading	1	1	0,034	-0,29
Awareness	How often do you notice the WHITE obstruction lights at the test centre Østerild? (1=Never, 7=More than 5 times a day)				
	… In the summer	5	5	0,003	-0,41
	… In the winter	5	4	0,000	-0,51
Perception of local area	What is your view on the qualities of the area? (1=Very unattractive, 5=Very attractive)				
	… Scenery	5	5	0,006	-0,38
	… Nature	5	5	0,005	-0,39
	How have the obstruction lights changed your sense of the skyline? (1=Much worse, 4=Better)	2	4	0,000	0,80

Table 7 Differences in mean between the 1st and 2nd survey for social impacts caused by the lights using Wilcoxon Signed Rank Test. (n=52).

The results show that the local residents are generally less annoyed by the obstruction lights after the installation of the radar-system compared to before the installation. This is the case when the weather is cloudy, when it is dark outside in the evening and at night. This is made evident by the fact that the median of the rank of the two distributions is lower after the installation of the radar compared to before.

The same tendency is evident regarding residents´ annoyance level during daily activities. Results show that residents are less annoyed by the lights when taking a walk, relaxing, or reading. The change is not detectable as changes to the median in these instances, as it is evident that the medians for the pre-, and post-radar survey are the same (Table 7). However, the p-value together with the effect size show that there is in fact a statistically significant negative change in the post-radar survey compared to the pre-radar survey. This means that the local residents are less annoyed after the installation of the radar-system.

The Wilcoxon signed rank test furthermore supports the results from the self-reported measures on awareness, finding that there has been a statistically significant change in the residents' awareness of the obstruction lights following the installation of the radar-system. The change is most noticeable in the winter (effect size=-0,51) compared to summer (effect size=-0,41). This is not surprising given that the impacts are presumably larger because of more darkness in the winter which makes the obstruction lights more visible.

The last factor that has changed due to the implementation of the radar-system is the citizens' perception of their local area. The results from the Wilcoxon Signed Rank Test point in different directions. The residents generally find the scenery and landscape less attractive after the installation of the radar-system, but their view of the skyline has, on the contrary, improved after the installation of the radar-system.

The conclusion to the Wilcoxon Signed Rank test and the self-reported results show that the radar-controlled light-system has succeeded in mitigating some of the social impacts related to annoyance and awareness of the lights, whereas the effects on the residents´ health and wellbeing are inconclusive. However, the radar-system has not managed to completely mitigate negative impacts caused by the obstruction lights. An example is annoyance. On this measure, results from the post-radar survey still show a relatively high percentage of the respondents (above 40 pct.) who are annoyed "to some extent" or "to a great extent" by the lights when they are driving, biking or taking a walk and at night, when it is dark outside in the morning and evening and when sky is clear. Consequently, as also indicated by the Wilcoxon Signed Rank test, the effects of the radar on social impacts are moderate.

A multiple regression analysis was conducted to understand the factors that influence particularly annoyance with the lights in order to understand why the radar-system only partially eliminated the negative social impacts from the obstruction lights.

	Beta (β)	*Sig. (p)*
Constant	27,021	0,014
Age	,021	0,810
Gender	,026	0,761
Education	,228	0,017
Economic compensation	-,210	0,041
Awareness of white lights	,063	0,579
Awareness of red lights	,020	0,823
Awareness of malfunctions	,291	0,006
Attitudes towards test centre	-,327	0,018
Attitudes towards wind energy	,197	0,098
Perception of the planning process	-,348	0,001
Adjusted R^2	.675	
Sig. model	.000	

Table 8 Multiple Regression Predicting perceived annoyance from socio-demographic factors, economic compensation. awareness of the lights, attitudes towards the test centre and wind energy, and perception of the planning process. (n=53).

The analysis identifies 5 factors that have statistically significant effects on the perceived annoyance with the lights: Education, whether the respondent has received an economic compensation in the planning process, to what extent the respondent is aware of the malfunctions to the light-system caused by the installation of the radar-system, their general attitudes towards the test centre, and finally their perception of the planning process related to the expansion of the test centre that took place at the same time as the 2nd survey.

Education has a positive influence on annoyance (r=,228), meaning that the more educated the residents are, the more annoyed they are with the obstruction lights. Economic compensation, however, seem to have the opposite effect (r=-,210), meaning that if residents have received economic compensation, it will lead to lesser annoyance with the obstruction lights. The positive effect from economic gain from planning processes is a tendency that is detected in other planning contexts as well.

Furthermore, the study investigated the effects of residents' awareness of both the white lights, the red lights and the malfunctions to the light-system and only awareness of the malfunctions has a statistically significant influence on annoyance (r=,291). The analysis shows that the more the residents´ noticed the malfunctions, the more they were annoyed by the lights. The malfunctions occurred primarily in the period when the radar was being implemented in the light-system. Among others, it was malfunctions such as too high intensity of the lights and asynchronous blinking. It is peculiar that awareness of the white and red lights had no significant effect on the residents´ annoyance. But the effect from the malfunctions might have been overshadowing the effects from the lights in general at the time of questioning because they were so much more visible and thus created more annoyance.

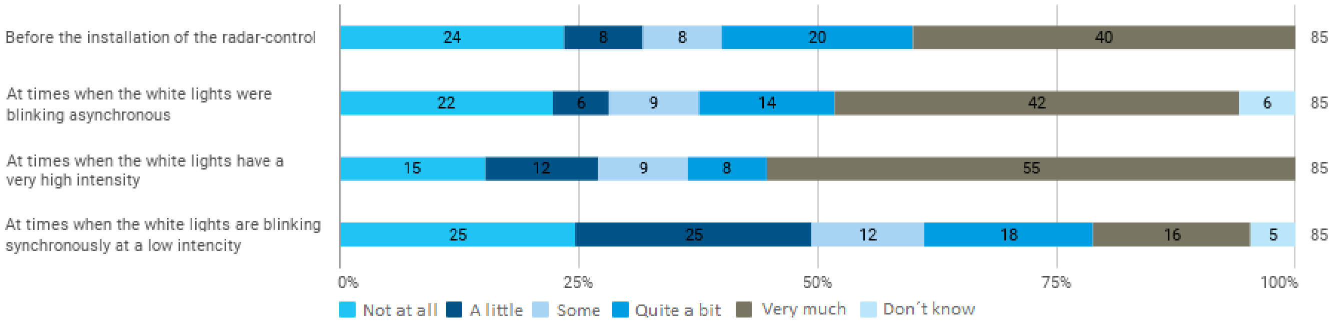


Figure 24 Answers to the question: To what extent have you felt annoyed by the white obstruction lights in the following periods…

Figure 24 shows the differences between annoyance with the lights before the radar was installed, when the radar was running with malfunctions and a hypothetical situation where the light-system performed optimally. Evidently, situations with malfunctions created more annoyance.

The results also show that residents´ attitudes towards the test center have a negative influence on annoyance (r=-,327). Respondents' attitudes are measured by asking how safe they feel living near the test centre and results show that the safer they feel, the less they are annoyed by the lights. Naturally, the question does not measure the full extent of the residents' attitude towards the test center which is multi-facetted, and the results can only be seen as an indication of an effect from attitudes on annoyance.

Finally, the effects from the respondents' perception of the expansion planning process are included. Results show that the more satisfied the residents were with the process related to the expansion of the test centre, the less annoyed they are by the obstruction lights. The effect is the strongest predictor of annoyance among the measured variables. Studies show that the citizens' perceptions of the procedural fairness and justice in a planning process often affect their attitude towards a project, but these results indicate that it also influences how they experience impacts created by the project.

The goodness of fit (R^2) is relatively high for the model tested here (.675) and the model explains more than 2/3 of the variance on the annoyance-variable. There is, however, still 1/3 of the annoyance that we cannot understand by use of the factors measured here. The fact that the radar-system has not completely eliminated annoyance with the lights is therefore not necessarily a failure on the part of the system but can be due to the fact that the annoyance is not only created by factors that have to do with the lights directly. It could be factors which have to be mitigated by other measures such as residents' perception of the planning process or whether residents have received economic compensation.

2.4.8 Findings from the post-installation interviews

After the radar had been installed, 7 personal interviews and 2 focus group interviews were carried out in order to get a deeper insight into people's perception on the lights and the processes in general. A range of themes emerged from these interviews, all providing a nuanced picture of the situation in Østerild and the future possibilities for strengthening the planning related to the test centre.

2.4.9 Perceptions of the lights

After the installation of the radar and the red light in 2017, the interviews reflected how things did not get better immediately. In fact, several interviewees described, how the installation of the radar actually worsened the state of things due the intensifying of technical problems. The lights are, in the long first period, as being totally irregular and unpredictable with significant shifts – changing from day to day and being very sensitive to any kind of air movements - including birds and clouds, as described by a male interviewee in 2017:

"I think it's best to illustrate it with a rain sensor in a car on windshield wipers. If it's very, very sensitive, the windscreen wiper can run like this, and then they run like this. So just if a cloud appears in front of the moon, then it starts to blink much more. If the cloud passes again immediately after 30 seconds or a minute, it goes back into full strength. So, it's so sensitive that I'd almost say that just if a bird flies along in the moonlight it regulates the brightness. It's extremely annoying ... " (Interview, 2017)

Particularly, the transition from the white to the red light during the twilight period is described as being very stressful. This transition was characterized by red and white lights running simultaneously, although in constant and varying forces for a couple of hours, before the flashes went into pure red light. The transition period is described as "uneasy" and characterized by a lack of continuity, and several interviewees described how the lights seemed to be "going crazy" creating modes of "light show" and "Tivoli" when both red and white lights were driving up and down in different intensities. In this respect, what was initially introduced as a technical improvement, i.e. the installation of the radar and the red light, actually turned out to be a deterioration for many months after the installation, as explained by a man in 2017:

"It also runs with red and white lights at the same time, and then white flashes and red flashes constantly, until it turns into pure red. But, then suddenly, a few hours during the evening, it makes some bright white blink, doing, doing, doing, and it may be at night while you are sitting watching the news, where I think: why, if it is to test if there is still light in the bulb, could you not then just choose to do it when we went to bed, instead of eight o'clock in the evening? (Interview, 2017)

The experience is described as being intensified by the fact that the twilight is precisely the time when most people return home from work and seek peace and relaxation. Thus, interviewees explain how the blinking caused dissatisfaction and irritation, because it collided with what is perceived as the private sphere. Compared with this turmoil, the invention of the steady red light (without blinking) is described as a relief. Interviewees describe how they find themselves standing and looking for the continuity of the red light, which is perceived as far less distinctive and bothering than the white light, although, as noted by several people, still not a pretty look. However, it is also described how, even during the night, the radar did not function as hoped for. Interviewees described how the radar was initially extremely sensitive to any sort of disturbance in the sky, and how they also experienced periodic fluctuations between red and white lights during dark hours, which were not deemed to be due to the sensitivity to flying objects alone, but also to testing. A common remark in this regard is that the promise to stop the blinking and testing around sundown has not completely been met. Based on such experiences, several respondents expressed how the situation before the radar was in a way easier to deal with, because at least you knew what to expect. Although the constant white flashing from the masts during day and night was annoying, at least it was continuous and without any big surprises. In that sense, the lack of rhythm and continuity and the situation of not knowing what is next have been described as frustrating and stressful.

The last three interviews (one personal and two focus group interviews) in May 2018 and the information meeting (November 2018) illustrated that the light regulation by the radar had improved. It was described how the radar only activated blinks from the masts when there *were* actually larger flying objects in the sky to which the radar *should* respond, and also, it was noted how the changes had taken place during the spring, noticing that the changes took place during spring (nearly a year after the installation of the radar), although some also noted, how the feeling of improvement had something to do with the days getting longer and brighter. Hence, even though the overall response from interviewees in May 2018 indicated that both the red and the white lights are not as annoying in daytime as before the radar was installed (only in case of a decisive drift disorder), the feedback from the information meeting in November 2018 indicated that the red and white light in the daytime was still an issue in their daily life. Some explained how they still experienced unpredictable white blinks in the evening and how the eye was always drawn towards the light while others explained that they were also annoyed by the white light during the day and physically turned their back to the light, while walking in the landscape in order to avoid it.

2.4.10 Place identity

People's annoyance with the obstruction lights cannot be detached from other issues, such as place identity. Hence, the issue of darkness reappears in the later interviews to symbolize a decoupling from a hectic lifestyle and a need for maintaining a slow rhythm in harmony with nature as opposed to everyday turbulence and a lack of continuity. In continuation of this experience, it becomes clear how the unstable control of the obstruction lights in the implementations phase endures to add to the experience of spoiled darkness instead of being a solution. Several interviewees described how the lights are in fact behavioural, because they naturally capture and focus the eye, this preventing one from gazing on the landscape as a whole. The light is described to control the way the landscape is perceived - not as something coherent, but as a particle in the form of the light from the test center. As described by a woman in 2018:

"The first thing that catches your eyes, when you look out the window in the morning is the turbines and when the dark comes, it's the light from the turbines". (Interview, 2018)

2.4.11 The planning process

Moreover, the themes of planning and communication continue to be an issue in the second and third rounds of interviews. In 2017 and 2018 interviewees had still been frustrated with the way the planning process had been handled. In general, there is the opinion that the communication and transparency with the public have been under-prioritized. The criticism is based on the initial experience of decisions taken well before the idea of the test center was presented to the citizens that caused distrust of the authorities, whereas several interviewees noted how the initial poor experience has lingered on after the installation of the radar. The criticism is especially due to promised but dragged on improvements in relation to the light marking as well as deadlines for the demolition of old turbines that were not complied with. The experience is described as a lack of a systematic information strategy, reflecting a random and incomplete information provision. For instance, it is mentioned how the feeling of uncertainty relates to the observation of lights "going crazy" and the lack of explanations as to what was actually going on. Hence, it is also explained how, especially after the installation of the radar, some residents started making their own systematic registration systems in search of at least some sort of order and overview of what to expect.

2.4.12 Living in uncertainty

Compared to former experiences, interviewees from the third round of interviews explained how the experience of uncertainty seems to repeat itself in terms of the forthcoming expansion process. People feel unsure what the future expansion process will actually imply, since the announcements from the authorities are constantly changing. Sometimes, the expansion is described as consisting of three test places, sometimes two, whereas the height of the turbines is described as getting bigger. The constant change of announcements creates uncertainty and is also described to capture local residents in a situation of impermanence. This is not least related to the individual exercise of planning for the future and taking decisions concerning one's personal life – for instance the purchase and sale of housing, as explained by a man in 2017:

"But, I would also like to say that our concerns also relate to the fact that, well, we do not know when this process is going to stop, is it what we see now or is it when we have signed a closing note and then suddenly, there is a 50-meter taller turbine next to it. Or are we being expropriated in a two years' time, because then they will install one more, that is, the uncertainty, when can we expect that the situation is final?" (Interview, 2017).

The issues concerning uncertainty due to the temporality associated with the test centre were also mentioned by several citizens at the final public meeting in 2018., It was emphasized that living close to a test centre implies unpredictable futures, which deeply effects local residents and their perceptions of their surroundings.

2.4.13 Suggestions for the future

A common understanding from all interviews is that improvements are being acknowledged, and that there are also many suggestions as to how the situation could be improved in the future. Several interviewees added to the existing improvement that a permanent (local) person is working at the test-center being responsible for keeping an eye on the lights. The same person is also available for answering questions from the local residents about the operation of the radar and is open for receiving information from the people in the area about any sort of registrations. The improvements are described as being of both a concrete physical and mental character. Besides from having resulted in a faster response to sudden irregularity of the lights, the very feeling of being heard and seen has also been appreciated.

As an alternative to the lack of information about the lights in particular and the future development of the test center in general, more openness during the planning process and continuity are requested by all interviewees. More specifically, the possibility of some sort of communication system (a website, a SMS, mail or, an app) was repeatedly mentioned as arrangements that could contribute to a reduction of uncertainty, and thus also potentially help to minimize the local resistance against the test center. As part of a more continuous information strategy about the planning process itself, more information about the lights and radar control was also requested: Such an innovation does not have to be very advanced. The opportunity itself, to get explanations of unforeseen episodes and to be made aware of upcoming planned actions, would help to create a possibility of reducing uncertainty:

"Yes, such a current operating report, where we were for instance told that in September the lights have run like this, and there have been some operational disturbances during those periods, but we continue to try to solve it, and there have been no light markings at night during the last few days, and this has been completely planned, because of some rescue operations - then you would think, now this was actually really nice to know" (Interview 1, p. 13).

2.5 WP5: Dissemination

Presentations (conference and public)

Date	Venue	Details
8/12 2015	Public meeting, Østerild Inn, Denmark	Results from the first survey presented to the local community
30/9-2/10-2018	Nordic Baltic Impact Assessment Conference, Estonia	Results presented at session: Critical reflections on social, cultural, economic, health impacts and stakeholder engagement in IA
31/10 - 2018	Wind Energy Denmark Conference, Denmark	Results presented at session: Social acceptability and environment
08/11-2018	Public meeting, Østerild visitor centre, Denmark	Results presented and discussed with the local community
15/11-2018	Institute of Social and Economic Research, University of Alaska, Anchorage, Alaska	Results presented to research group

Journal articles

Date	Title	Journal
Published 2017	Spoiled darkness? Sense of place and annoyance over obstruction lights from the world's largest wind turbine test centre in Denmark	Energy Research & Social Science
Forthcoming	Mitigating spoiled darkness? Effects of on-demand radar-control on negative impacts from aviation obstruction lights on wind turbines	Forthcoming
Forthcoming	*"We got used to it, but…."*. Ambivalent coping strategies with wind power induced landscape change around Østerild	Forthcoming
Forthcoming	Comparative Study between Denmark, Germany and Switzerland	Forthcoming

Media dissemination

Date	Title	Paper
23/9-2015	Asks questions regarding the lights from test centre in Østerild	Thylands Avis (local newspaper)
03/11-2015	More knowledge of the lights from pylons	Morsø folkeblad (local newspaper) Thisted Dagblad (Local Newspaper)
3/12-2015	Difficult to get used to the blinking lights in the air	Morsø folkeblad Thisted Dagblad Nordjyllands Stifttidende (regional newspaper)
10/12-2015	Locals want the darkness back	Thisted Dagblad
10/12-2015	The finger is ready on the switch	Morsø Folkeblad
19/12-2015	Public meeting regarding obstruction lights	Thisted Posten (Local newspaper)
20/12-2015	No deadline for the lights at the test centre	Thisted Dagblad
2/3-2018	Wants answers regarding the lights at Østerild	Thisted Dagblad Morsø Folkeblad
30/10-2018	The night has become darker in Østerild: Fewer experience nuisance from the lights at test centre	Nordjyske Stifttidende
2/11-2018	Radar technology improves neighbourliness with wind turbines	Energy-supply.dk (national newsletter)
11/11-2018	Dark night – almost as it was before	Nordjyske Stifttidende

In addition, the project has throughout the project period maintained a Facebook page where the results from the project have been disseminated. Link:

https://www.facebook.com/groups/1640696232869046/

2.6 Utilization of project results

2.6.1 Østerild OLC radar test and verification

At the time, where the agreement with DTU Wind Energy was established this installation was going to be the first of its kind in Denmark, and consequently also categorized as a pilot/test installation. Hereby also acknowledging that some challenges were to expect in order to get the OLC system installed, tested, verified and approved for operational use. Apart from some minor technical issues the far most severe challenge was to obtain formal approval. This was mainly due to the fact that no formal regulatory exists and exemption from BL 3-11 had never been granted on a OLC installation before. So basically, the Danish Transport, Construction and Housing Authority also needed to learn about such systems and subsequently in the hearing process, also discuss/agree with the Danish Defence Command on how this could be applied. Finally, DTU obtained the approval and their OLC installation in Østerild could go into formal operation.

Both in the test and verification process, described in section 2.1 and in other specific customer projects valuable experience and knowledge gathering has taken place with a clear aim to optimize and finalize the OLC product solution being offered to the wind industry.

Specifically, we have now obtained official OLC authority approval in both Germany and US, as these nations are the only one having a formal regulatory. Furthermore, the first 2 system are in operation in Germany today and 10 more system are under contract to go operational during 2019.

On this basis, it is fair to say, that the Østerild project has been a true enabler for bringing Terma in a very good market position.

Looking further ahead, several nations are currently drafting OLC regulatory by push from local wind industry and in this situation, it is very convincing that Terma is able to provide such national authorities with technology from proven operational OLC radar systems.

2.6.2 Regulatory recommendations

Through the project we have taken all experiences from the Østerild project together with international projects learnings and utilized those to derive some quite detailed own requirements for an OLC system. Such requirements are probably not final and conclusive, but at least a quite good basis for drafting a Danish regulatory on OLC systems.
Utilizing these, recommendation for a Danish OLC regulatory, which has been derived through this project should to a large extend represent best practice on this topic. One of the initial project objectives in the associated WP 3, was to identify possible subject matter experts being able to perform formal peer to peer review for such draft OLC regulatory, but unfortunately, this has not been possible, so far.
Consequently, the clear recommendation from here is to continue this effort in getting a OLC regulatory established as we think the basis for that is provided though this project.

2.6.3 Recommendations based on social impact analyses

Based on the analyses of the social impacts caused by the obstruction lights and the installed radar, two main recommendations can be made that will contribute to making radar-control of obstruction lights a useful instrument mitigating the social impacts from obstruction lights in local communities:

1) The implementation of an OLC radar should be accompanied by extensive communication regarding realistic efficiency of the radar-control OLC system and information related to any malfunctions in order to reduce unrealistic expectations and uncertainty in the community.

2) Initiatives that would support this recommendation could be:

   - A local contact person at the test centre who is reachable for the local community at a daily basis for questions and suggestions

- The set-up of a communication system that reaches the local community (e.g. a website, a SMS service, mail or an App) which would be used to illustrate efficiency and accounting for malfunctions, changes to the system or the like.

3) Since fairness and justice in the planning process influence the perception of the impacts from obstruction lights, special attention should be given to transparency and communication already in the planning and hearing process.

3. Project conclusion and perspective

The CORAL project was applied for, under the EUDP 14-II program in parallel with the installation, test, verification and approval of the Østerild installation.

CORAL has been Terma's first project under the EUDP program and consequently also the first experience with EUDP. Fortunately, we have had two very competent partners in the project – DTU Wind Energy and AAU, who both were quite experienced in running EUDP projects, so we think, that this all in all has been a good match.

Looking at the original project objective, the basic content of the project is a technical part and an environment/social impact part, where Terma has been leading on the technical part, whereas DTU and AAU have been leading on the environment/social impact part.

In summary, the technical aspects of the project have been very successful as also indicated in previous section. Our starting point was trying to enter a new market domain with some existing technology, we thought were applicable. Through the project we have learned a lot on the technical aspects an OLC system and through the project gained the necessary experience to refine the solution into a market proven product. On that basis we have obtained formal approval of the solution in both US and Germany as well as being able to sell a significant number of systems on that account.

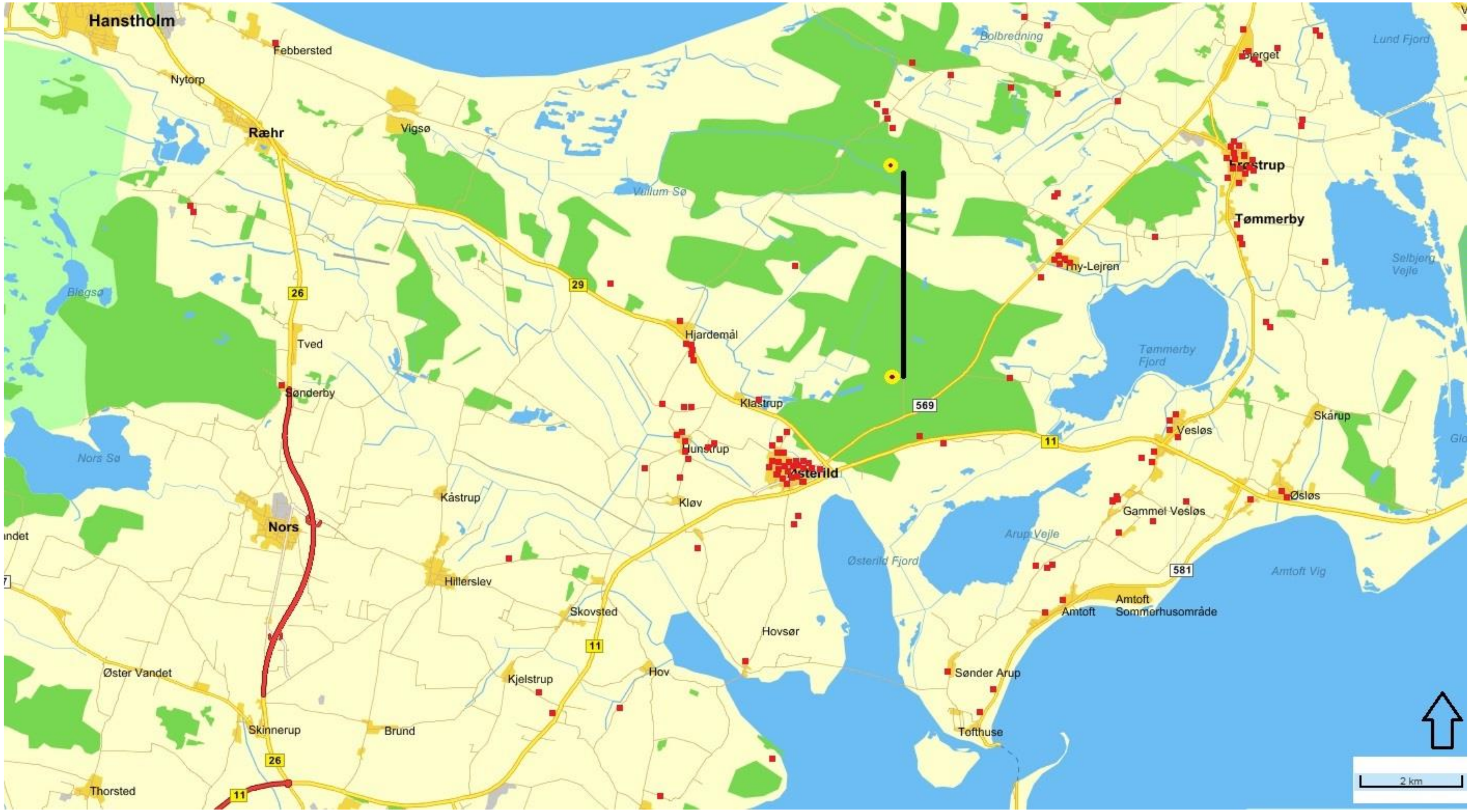
Additionally, also through the CORAL project we have obtained a good understanding of the requirements for OLC systems, which also are the basis for the draft Danish OLC regulatory set forth in this report.

Furthermore, this has put us in a position to participate in various meetings advising other nations workgroups and authorities on the matter.

In terms of people's perception of the lights, it can be concluded that the operation of radar-controlled lights has reduced the awareness of and mitigated the annoyance by the lights. In general, the survey results show that local residents tend to be less annoyed by the obstruction lights after the installation of the radar, given the system works properly. However, the effects of the OLC on social impacts are moderate and changes in the perception of the landscape are inconclusive, which, however, cannot be separated from the multi-facetted attitudes towards the test centre.

Annex A

Map of respondents - 2nd survey.



Annex B

Spoiled Darkness - full article.

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Original research article

Spoiled darkness? Sense of place and annoyance over obstruction lights from the world's largest wind turbine test centre in Denmark

David Rudolph[a,*], Julia Kirkegaard[a], Ivar Lyhne[b], Niels-Erik Clausen[a], Lone Kørnøv[b]

[a] *Technical University of Denmark, Department of Wind Energy, Risø Campus, Frederiksborgvej 399, 4000 Roskilde, Denmark*
[b] *Aalborg University, Department of Development and Planning, The Danish Centre for Environmental Assessment, Rendsburggade 14, 9000 Aalborg, Denmark*

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ABSTRACT

The relation between wind power development and local communities has received considerable attention in literature and practice. Relatively few studies, however, have provided evidence about how local citizens perceive enduring environmental impacts such as aviation obstruction lights installed on wind turbines or on wind farm light masts. Evidence regarding people's perceived annoyance over obstruction lights is of increasing importance as wind turbines become taller, thus potentially affecting more people in the future. The paper conducts individual web-based surveys and interviews with local residents around the world's largest onshore test site for tall wind turbines in Denmark – the national test site in the rural area of Østerild. The aim is to explore the nature and extent of perceived annoyance over aviation obstruction lights from the test site and the efficiency of different coping strategies. In particular, the discussion focuses on the perceived annoyance in relation to the perceived changes in sense of place, hereunder the loss of the area's unique night darkness. We argue that perceived annoyance can only be mitigated through coping strategies to a limited extent, as a) perceived effects on sense of place are distinctive in shaping annoyance, and b) an internalisation of planning-related inequities persists.

1. Introduction

A significant number of researchers have studied the relations between wind power development and citizens' reactions, with a special focus on social acceptance [e.g. [1–5]]. Paradoxically speaking, while research supposes that initial concerns and resistance wane after the realisation of wind farms, and that the majority of residents appear to at least tolerate the projects if impacts are adequately dealt with [5,6], relatively little is known about how the enduring impacts may pervade people's everyday lives after the construction of wind farms [7]. It is crucial to develop a better understanding of the factors shaping people's responses to wind farm development by not only examining the concerns and envisioned impacts at the planning stage, but also once infrastructures have been constructed and become operational [8].

One particular type of impact from wind power that has received less attention is aviation obstruction lights. Requirements regarding obstruction lights differ across countries, e.g. in terms of colour, light source and flash frequency [9]. Research in Germany and Switzerland has documented a substantial annoyance caused by different aviation obstruction light technologies [10–12], which demonstrates a potential conflict between wind power ambitions, flight safety and the values and health of local citizens. In order to manage the trade-offs between wind power, aviation safety, health impacts and social acceptance, it is important to investigate and document the impacts of different obstruction light technologies and solutions on local citizens.

As wind turbines are consistently increasing in size and height, obstruction lights will always be required for flight safety, and will thus be visible from a greater distance; indeed, this could potentially annoy more inhabitants [13]. Given this development, obstruction lights on wind turbines are likely to become increasingly important in terms of citizens' perception and reaction. This paper adds to the limited existing knowledge about enduring impacts from obstruction lights by reporting on perceived annoyance among local citizens from what is termed the world's largest test site for large wind turbines [14]. Located at an onshore test site in Østerild, Denmark, these wind turbines have an installed capacity of up to 8 MW and a current height of up to 222 m. The Østerild test site is unique insofar as it is a nationally designated test site designed for testing prototypes of large (up to 250 m tall) offshore wind turbines on land. Thus, the wind turbines are gener-

* Corresponding author.
E-mail addresses: david.p.rudolph@gmail.com, dpru@dtu.dk (D. Rudolph).

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ally taller than seen at other wind farms on land, and consequently the required level of obstruction light markings for aviation safety is more demanding, demanding white flashing lights mounted on to two light masts, making it an interesting site for a study. Moreover, the planning process of the test site was characterised by a top-down approach, leaving very little leeway for actively taking into account people's concerns other than upfront concessions based on compensatory measures. Furthermore, the test site's location in a largely rural area which benefits from unique characteristics such as an unspoiled, dark night sky, implies that the impact of the obstruction lights may be seen as more intrusive and detrimental to the sense of place than in other areas. The unique case of the test site for large wind turbines in the rural area of Østerild is therefore interesting due to its particular technological, institutional, and place-based characteristics, but also reflects the importance of that issue.

The aim of this paper is to explore the nature of local perceptions regarding the impacts of the aviation obstruction lights from the test site for large wind turbines through individual web-based surveys and interviews with selected local residents. While it provides a unique case, the study adds to the limited knowledge base regarding perceived annoyance and coping strategies from obstruction light technologies, particularly in regard to the effects of flashing lights during night time from very large wind turbines. The study furthermore contributes to the understanding of the concept of annoyance and the relation between perceived annoyance and sense of place. As part of this relation, the paper focusses on the issue of the loss of night darkness as a perceived deterioration of uniqueness and distinctiveness of the place [15], and how the lost quality of darkness adversely impacts the efficiency of coping strategies.

2. Obstruction lights, annoyance and local responses

The relationship between visual impacts of obstruction lights on wind farms, sense of place, and perceived annoyance has rarely been considered. This section positions our study of obstruction lights in these notions, and provides a framework for the empirical analysis.

2.1. Research pertaining to aviation obstruction lights on wind turbines

Research regarding the visual impacts of wind turbines has predominantly focussed on individual perceptions of turbines [e.g. [16,17]] and the assessment of the visual presence of wind turbines in the landscape and seascape [e.g. [18–21]]. Obstruction lights on wind turbines or wind farm light masts are generally only indirectly considered as part of visual impacts [e.g. [16,17]].

So far, only a group of German researchers has extensively studied the significance of visual disruptions through light pollution from wind turbines and analysed the perception of and annoyance resulting from wind turbine obstruction lights [11,12,22]. They compared the stress impacts of different aviation obstruction markings on people living in the vicinity of several wind farms in Germany and Switzerland by using the survey methodology. While their survey did not find any evidence for disease-promoting stress effects induced by obstruction markings, it did reveal differences in the nature, quality, and extent of annoyances, disturbances, and coping strategies related to certain types of obstruction markings [11]. The visibility of the lights due to changing weather conditions and natural light during day and night were also identified by the group as a key factor for eliciting annoyances, as the lights were perceived as more disruptive on cloudless nights than on misty days. Light intensity adjustments were also identified as another factor affecting the degree of perceived annoyance.

Obstruction lights have furthermore been explicitly considered in studies concerning the detrimental effects of wind turbines on animals, particularly with regard to attracting lights as a cause of collision fatalities for birds and night-migrating bats [23–25]. This is an issue that has also been discussed in relation to the lighted markings of other infrastructures, such as communication towers [26]. More generally speaking, research on aviation obstruction lights relates to studies of artificial light sources as environmental problems [27–29]. This field of research points to the perceived value of experiencing darkness and lightless places in a world which is becoming increasingly over-illuminated [30].

2.2. Sense of place and darkness

Places do not have an inherent meaning, but gain significance through various meanings ascribed to them by humans. Therefore, places not only become relevant as the spatialised setting or physical location for social activities, but also incorporate values, emotional attachments, social relations and identity. The notion of *sense of place* captures 'the conscious awareness of locatedness and distinctiveness between places' [31,p.63] that is 'embedded within the social, economic, and cultural relations that provide the setting for everyday experiences on a more local level' [32,p.91]. A focus on sense of place allows for a better understanding of how technical activities, such as the siting of energy infrastructures and their associated implications, can encroach upon people's feelings and perceptions about where they live and potentially affect certain values ascribed to this place [32]. Changes of sensory and aesthetic experiences may alter or threaten the meanings ascribed to places depending on the underlying individual and symbolic meanings associated with these places and envisioned changes [33,34]. The visual impacts of wind farms are generally seen as a factor that can change the relationships between certain landscapes and the people who occupy, cherish, value or appropriate them [19,35,36]. Expected or feared visual intrusions have become a common argument underlying protests [37], as they may alter sensory qualities of places by creating unwanted sights and views and thus disrupting a place-related continuity and familiarity of individuals [33]. This can then not only lead to disruptions of the positive emotional ties of the self with familiar places, such as home and neighbourhood [38], but can also be projected onto expected reactions of others, especially the place-related aspirations of tourists [39].

However, visual impacts have not yet been explicitly put into the context of obstruction lights as a potential interference and disruption of place-based relations. While the perception of obstruction lights has remained largely disregarded, the meaning of darkness has gained more importance in place-related research, with many describing it as a powerful agent in the production of atmospheres [40]. The role of a dark night sky has also been highlighted as a central element when it comes to sensory and affective experiences of landscapes and places [30,41,42]. Shaw [43] has provided an overview of the breadth of nocturnal social sciences and stressed the multiplicity of lived and experienced nights by conceptualising the night as a frontier. He argued that the gradual return to darkness has a transformative potential for understanding the self and landscape, and also hinted at the place-shaping capacity of representations of darkness.

2.3. Citizens' perception and annoyance of wind power

As the previous subsections indicate, annoyance has been referred to as a central term in describing the perceived impact of wind farms in general and obstructions lights in particular. However,despite extensive research on annoyance, including degrees of annoyance, the terms 'perception' and 'annoyance' have rarely been explicitly defined. Annoyance seems to be related to a range of other concepts in the literature such as perceptions, attitude, stress, and acceptance [e.g. [44,45]]. Annoyance is thus conceptually related to significant theoretical work on acceptance and attitudes that spans several theoretical disciplines [46].

The concept of annoyance was investigated by Guski et al. [47] in terms of noise. Following a survey of 68 noise experts they found that common grounds in conceptualising noise annoyance included a) an outcome, b) a multi-faceted psychological concept, c) mostly related to terms such as "nuisance" and "disturbance", d) a concept with different meaning depending on culture. In a study of annoyance related to the exposure of environmental factors, Lindvall and Radford [48,p.3] define annoyance as "a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them". In a German study regarding the annoyance of aviation obstruction lights [10], the authors used "Belästigung durch", which equals "annoyance by/through", and relates to a source as the nuisance. Inspired by the above, in this study perceived annoyance is considered as a feeling of displeasure directly or indirectly related to an emitting source, i.e. the obstruction lights.

Individuals' perceptions of effects and risks are highly influenced by their values and emotions [49,50]. Therefore, the social, cultural and spatial and temporal setting and context, in which people are embedded, influence their perception of the risks and impacts of activities. Perception and annoyance are thus based on subjective judgements and constructions of impacts and risks, utilising and internalising heuristics and simplified information, which has been framed as the psychometric paradigm [48].

Concluding on the above, citizens' perceptions and annoyance from obstruction lights are thus a complex phenomenon for investigation. Annoyance is, in part, related to geographical, meteorological, and temporal factors, and is also related to socio-cultural place attachments and informed by the individual's psychological processes. To disentangle this compositional complexity of perceived annoyance, the study reported on in this paper is concerned with the first two aspects, hereunder a) behavioural coping strategies and practices among local residents to mitigate the physical impact (e.g. engaging in opposition groups, installing blinds, talking to people, taking sedatives), as well as the efficiency of different coping strategies, and b) psychological effects on local residents from the lights under different conditions and time of the day, as well as perceived changes in the sense of place. The paper hereby inquires into the relation between sense of place and annoyance.

3. The test site for wind turbines and their aviation obstruction lights

The world's largest test site for very tall wind turbines in Østerild measures 346 ha and includes a row of seven turbine test spots. The companies which test their prototype wind turbines at the test site represent globally leading wind turbine manufacturers from Denmark, Germany and China respectively. As of April 2016, the test site has been occupied by seven test turbines with a capacity of between 2 and 8 MW, which are owned by Vestas (3 turbines), Siemens (2 turbines) and Envision (1 turbine). The tallest wind turbine so far is a Vestas' turbine (V164 8 MW) boasting a tip height of 222 m. One further wind turbine is planned to be installed by the French company EDF, which will fill the last of the eight available spots at the test site [51].

The test site is located in the Østerild dune plantation, which is situated in the municipality of Thisted in Jutland, in the North-Western-most part of Denmark close to the North Sea (see Fig. 1). This area was chosen due to the average wind intensity and the low population density [52]. As the result of a high-priority and relatively top-down national planning process, the world's biggest test site for large wind turbines was inaugurated in October 2012, under the daily leadership of the Wind Energy Department at the Technical University of Denmark.

The area of the Østerild Dune Plantation is characterised by a continuous green belt of plantations and sand dune heaths as well as dark night skies [53 p.7], [54]. Although relatively small in geographical terms, the area of Thy and Vester Hanherred (including Hannæs) boasts a strong and distinctive local culture and sense of place (Interviewee). Much like other places in the largely rural parts of North-Western Jutland – an area in Denmark far away from the capital of Copenhagen – inhabitants of this area are conventionally characterised as industrious, stubborn, self-reliant, taciturn, suspicious of State authorities, and parochial [55]. Located on the West Coast and with a decreasing population size [56], the peripheral Thy area is part of what is increasingly being dubbed as 'Outskirts-Denmark'. In order to overcome its reputation as a poor, harsh, remote and deserted area of Denmark, Thisted Municipality has attempted to brand Thy as a piece of Denmark's unique wilderness and as a stronghold for wind energy [57].

3.1. The test site and requirements for aviation obstruction lights

The wind turbines at the test site in Østerild are allowed to reach a height of 250 m (to fit the testing of wind turbines for offshore conditions) while the test site is governed by international aviation rules [58,p.90], stating that turbines above 150 m must be marked or lit with red lights mounted on the turbine nacelle; indeed, this is because they reach into international airspace, and thus constitute obstacles to avian safety. In the case of the Østerild test site, the Civil Aviation Administration (SLV – now Trafikstyrelsen) of Denmark accepted a particular arrangement for the aviation obstruction lights due to the particular use of the site for testing (meaning wind turbines are regularly exchanged/changed) and its proximity to Thisted Airport (approximately 10 km away). This special requirement comprised the construction of two 250 m tall lattice masts at each end of the test site with three levels of high-intensity,and flashing white lights instead of individual red light markings mounted on each turbine nacelle. The flashing of the lights is synchronised and has three intensity levels: day (high), dusk (medium) and night (lowest). Furthermore, the installation is equipped with a visibility-sensor, which automatically increases the light intensity in case of poor visibility (e.g. fog). While the Environmental Impact Assessment (EIA) for the Østerild test site described the need and technical specification of the obstruction lights on the light masts, it does not provide much detail on potential impacts of the obstruction lights, other than stating that "flashing white lights will affect the near and immediate zones and give the nature a character of a technical landscape, even if it is dark" [54,p.108]. During the consultation process, obstruction lights received limited attention, although discussions revolved around visual impacts and contested visualisations in the EIA. Only the Outdoor Council and the Danish Association for Nature Conservation raised concerns about noise and light pollution arising from the turbines affecting the area's silent and dark nights. They stated that noise and lights from the turbines would have a negative impact on the experience of day and night [53].

After the installation, local residents sent a large number of complaints about the lights to the authorities. The complaints and concerns about the obstruction lights led to an agreement, in 2010, to identify alternative solutions for marking wind turbines taller than 150 m as well as light masts [59,60]. One of the potential solutions to be considered was radar-controlled obstruction lights.

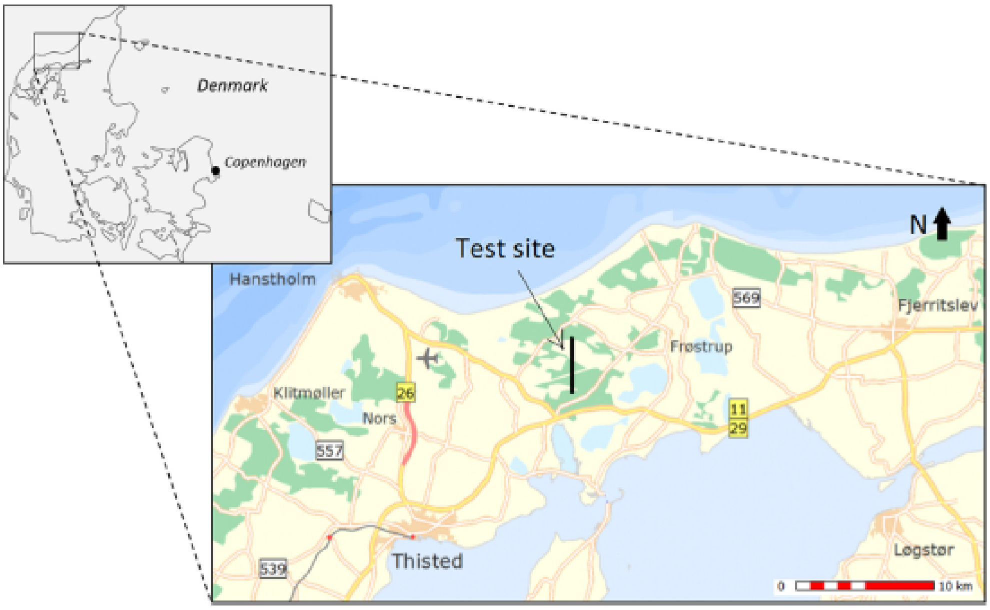

Fig. 1. Location of Østerild test center for large wind turbines in Northern Denmark (google).

4. Methodology

With the aim of investigating citizens' perceptions of the obstruction lights at Østerild, this study is based on both quantitative and qualitative data collected during an eight-month period spanning May–December 2015. The data were collected through an online survey, semi-structured interviews, and observations in the area. The number of survey respondents was 157, whilst in-depth interviews were conducted with seven people, and short interviews were carried out with approximately 70 people. The quantitative data from the survey are included in the analysis through descriptive statistics in figures and tables, whilst the qualitative data are represented in the analysis through quotes from the interviews as well as from the open questions of the survey.

4.1. *Semi-structured interviews, observations, and desk-based research*

In regard to qualitative data, semi-structured interviews [61,62] were conducted with local people living in the vicinity of the test site in June 2015. Interviewees were selected based on a) relevant written comments to the public consultation phase of the planning of the test site, b) residence close to the test site, and c) divergent profiles among the interviews in terms of distance from the site and profession. The content of the interviews was based on findings in the existing literature regarding stress and annoyance related to the perception of light pollution outlined above; it also related to desk-based research regarding the test site and surrounding area, the top-down planning process, and the public consultation responses to the EIA. The aim of the semi-structured interviews was to provide an informed basis for the formulation of survey questions. The interviews helped in identifying the specific wording and language employed by local people when referring to annoyance and the obstruction lights as well as mapping the main concerns and coping strategies undertaken by the local people. The local understanding of annoyance is in line with the definition based on the literature in Section 2.1. In total, six face-to-face interviews and one telephone interview with local residents were conducted and recorded. Interviews were conducted in teams (four in Danish and two interviews in English) and lasted between 0.5–1.5 h.

Observations were also undertaken in the local communities in order to identify how topography and local geographical conditions influence the visibility of the aviation obstruction lights in the area around the test site. While taking advantage of a national poll in June 2015, four researchers conducted short informal conversations with people around different local polling stations and in local grocery shops. At a public meeting held in December 2015 in Østerild – presenting the preliminary survey findings – observation data from local participant responses were also gathered, to inform the analysis of findings.

Based on the interview and observations, the zone of visual influence was established as preparation for the survey. The number of addresses in the zone of visual influence was calculated using GIS software to estimate the potentially affected residents. In turn, this was validated by the on-site observations in order to account for differences in local vegetation, which made distances insufficient in terms of predicting the visual impact. Other means of validation consisted of the EIA report and photos taken from the top of the southern light mast at 244 m (March 2015). In terms of the size of the local population in affected areas, 5 addresses are placed within a 2 km radius of the test site, 400 within a 5 km radius, 5000 within a 15 km radius, and 19,000 within a 30 km radius. Due to these numbers and data from the German study of obstruction lights [11], the intended number of survey respondents was 200.

The information gathered through the described methods was used to develop and interpret the results of an online survey designed to assess people's perceptions of the obstruction lights, their potential effects, and coping strategies that can be employed.

4.2. Survey methodology

The survey, consisting of 30 questions in total, was translated into Danish and tested amongst selected people before being disseminated online in Sep.–Dec. 2015 using the software tool *SurveyXact*. The questions were developed based on the researchers' own research questions and preliminary findings, while inspiration was also drawn from a previous study conducted in Germany [11]. Perceptions of the obstruction lights were used as a measure of the extent to which people are bothered, and how and whether different coping strategies may mitigate annoyances. Hence, the survey focussed on understanding people's perceptions of the lights, i.e. how people perceive the obstruction lights, and hereunder how they are influenced/annoyed by the lights. Similar to Pohl et al. [11], the survey attempted to (1) distinguish the actual annoyance from general attitudes and values, (2) distinguish the impacts related to obstruction lights from visual impacts of the wind power and light masts and from other impacts like sound, and (3) map how and when people are annoyed.

In order to minimise bias, the questionnaire started out at a general level, dealing with people's perceptions of the local area and recent changes in the community landscape, rather than beginning with a focus on the issue of obstruction lights. In this way, the survey only gradually delved into the issue of the lights and their potential annoyance. Following this were questions related to people's perceptions of the obstruction lights, and then questions relating to the extent to which people feel that they are negatively affected by the test site. The final questions related to people's background (age, profession etc.) and potential contact information. Informed and inspired by Pohl et al.'s [11] study and its psychological focus on people's perception, a number of questions also related to people's general physical and psychological well-being and the efficiency of individually adopted coping strategies. Based on the data, descriptive statistical analyses were applied, detecting relations between selected variables. Since the survey included personal data including addresses and illness, confidentiality was a key priority.

The recruitment of respondents involved leaflets, a public meeting, a Facebook site, posters in local shops, and newspaper articles. The leaflets were thus disseminated face-to-face during observation activities and circulated in mailboxes at selected addresses in the surrounding area and at several central places in the communities (e.g. sports halls, schools, shops). The public meeting presented the study and related initiatives; it was held in Østerild in December 2015. A Facebook site and group (215 followers) were created to recruit respondents and to keep local people informed about the study. Four articles were published in the local newspaper in cooperation with a journalist (Thisted Dagblad). Lastly, a competition offering prizes including bottles of wine and a box of chocolates was announced in order to encourage more people to participate.

The total number of respondents was 157. Of these, 149 fully completed the survey, whilst 8respondents refrained from answering a few questions, but were deemed to be valid following a double-checking of the data. This number is not expected to provide a representative sample of the local population, but it allows some insights into people's perception of the obstructions lights. Due to the limited number of respondents and the non-probability sample, inference was limited and regression analysis was not deemed feasible, and the analysis thus only reports on descriptive statistics. In particular, a pilot regression analysis did not show any significant results with regard to what variables determine annoyance. Only very few parameters (direct visual contact with the lights from the own property and participation in an opposition group as a coping strategy) were statistically significant, which however did not allow for any substantial statements as to what determines annoyances or its mitigation. A further limitation was that respondents who are bothered by the lights might be over-represented:

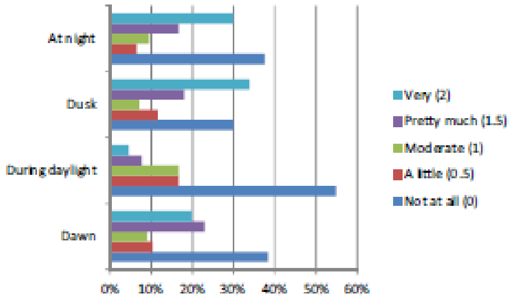

Fig. 2. Perceived annoyance during day and night. N = 157. Mean(M) and standard deviation (SD) of annoyance: At night M = 0.87 (SD = 0.90); Dusk M = 1.05 (SD = 0.95); Daylight M = 0.34 (SD = 0.59); Dawn M = 0.72 (SD = 0.89).

During the recruitment activities, a high percentage of the local citizens expressed little or no concerns over the lights, although the survey sample was dominated by annoyed respondents, some of which were summer house residents and/or had moved to the area relatively recently to enjoy the unique landscape qualities, e.g. darkness. Other bias related to the convenience sampling and difficulties in completely disentangling people's concerns over the lack of public participation in the planning process from concerns over the test site in general and the lights in particular.The findings may also be biased due to a loss of semantic meaning in the translation from local dialects to English. Finally, the responses should, as emphasised in Section 2, be seen as subjective statements of annoyance, as the investigation was not geared towards documenting the physical or psychological impacts from obstruction lights according to a medical standard.

5. Empirical findings on citizens' annoyance from obstruction lights

This section is concerned with the empirical findings on perceived annoyance from obstruction lights amongst local inhabitants. The section summarises findings on perceived annoyance under different conditions, citizens' behavioural changes and coping strategies, their effect on perceived annoyance, and the relation between annoyance and sense of place.

5.1. Perceived annoyance from obstruction lights under different conditions

In line with the German studies on perception of obstruction lights [e.g. [11]], the perceived annoyance from obstruction lights differed across season and time of the day, and depended on the weather conditions as well as on citizens' activities. As expected, the annoyance from flashing aviation obstruction lights was less severe in daylight, and highest during dusk (see Fig. 2). The maximum annoyance was at dusk, with 34% stating they are very annoyed, and 18% stating they are pretty much annoyed at this time of the day. The influence of weather conditions is obvious in the data and annoyance was, as an example, higher when the sky is clear. However, the interviews demonstrated that for some citizens, foggy weather conditions lead to increased annoyance: "[Annoyance is higher] when it's foggy, because the reflection is so strong, when it's foggy" (interviewee).

Since there is no absolute measure for perceived annoyance, the survey allowed for comparison with other annoyance from landscape changes caused by the test site (see comparison with annoyance from landscape changes in Fig. 3) and other light sources

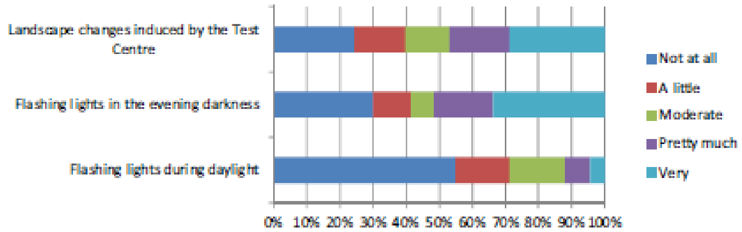

Fig. 3. Perceived annoyance from flashing aviation obstruction lights compared to perceived annoyance from landscape changes induced by the test site. N = 111.

such as from other wind turbines, street lights, traffic, buildings and TV masts. The data indicated that annoyance from the flashing obstruction lights in the evening darkness is comparable to the annoyance from landscape changes caused by the construction of the test site and the wind turbines.

The micro-geography around and inside people's house plays a determining role when it comes to the level of perceived annoyance. The data showed that the extent to which people noticed the lights depended on factors such as whether there are trees outside the window to offer shading from the lights, whether or not the house faces the test site, whether the house is close to water, which will lead to reflection in the water, and whether or not the bedroom windows are facing the test site. In addition, the data showed that some people living closer to the lights seem to be less annoyed, because the test site appears to be hidden behind the plantation forest. One interviewee presented a hypothesis regarding the influence of the micro-geography: "People in Østerild don't notice them because they live too close. I think there's a certain distance from where it gets really bad" (Interviewee 1 (female; employed; living outside of Østerild; native)). The data thus gave rise to the argument that distance does not allow for a sufficient explanation of the degree of perceived annoyance, since micro-geographical and weather conditions substantially affect people's perception of, exposure to, and relation to the lights.

But people's degree of annoyance relates to the frequency of perceived disturbance; indeed, people who repeatedly noticed the lights stated that they are very much annoyed by them, especially at night and during twilight (see Table 1 and Fig. 2). This suggests that exposure to the light masts is a determining factor of annoyance. The figures in the table indicate that a notable amount of the moderately annoyed citizens are only seldom noticing the lights. Meanwhile, the interviewees explained that just knowing that the turbines are there is enough to feel annoyed. The figures also indicate that a group of the not annoyed are disturbed by the lights every day. Both deviations from the relation between disturbance and annoyance emphasise the complexity of annoyance.

Finally, annoyance also seems to be influenced by the planning and construction process. The impact of the obstruction lights on the local community and landscape had not been assessed and described in detail in the EIA and the flashing lights were therefore a "a shock to us when they were turned on" (Interviewee 2 (female; employed; living in Østerild plantation; incomer)). In addition, the software for operating the lights was adjusted incorrectly during the first few months, which led to a much higher light intensity than intended. This was stated numerous times by local citizens, who referred to the failure and the planning process when articulating their perceived annoyance. One interviewee made a direct link between the obstruction lights and the planning process of the test site: "Every time I see the lights, I remember the awful planning process" (Interviewee 2 (female; employed; living in Østerild plantation; incomer)).

The level of annoyance has, in turn, changed over time. However, in contrast to other studies, the change in annoyance was not unequivocal: In the past three years, 34% of the 157 respondents admitted to having become less annoyed, whilst there was no change in annoyance for 52%, and 16% stated that they had become more annoyed by the flashing obstruction lights. Hereby, the survey data pointed to how annoyance has only been reduced to a limited extent over time. In particular, annoyance levels seem to increase when they realise that their activities are continuously being impacted and when they lose hope of positive changes to the light flashes. Conversely, the data pointed out how increased tourism and the practical use of the lights masts for orientation act as factors which can lower annoyance levels.

5.2. *Changes in behaviour and limited effect of coping strategies*

While annoyance levels are influenced by the time of day, weather conditions, and micro-geography, interviews and survey results also showed that local residents were affected differently by the lights, depending on the type of activity they are engaged in. Whilst people were not noticing the lights much when working, they tended to be much more prone to disturbance when engaged in leisure activities, such as TV-watching, walks in the nature, star-watching or bird-watching. Whereas this difference may be explained by e.g. the time of the day of the activity, the interviewees explicitly refer to values, when explaining the impact on leisure activities. Indeed, as stated by one respondent:

> "We cannot go out at night and enjoy a nice clear, starry sky, or take an evening walk in the dark, because the flashes disturb and dazzle in clear weather when they are reflected in the water. There is a constant flash light in the evening" (survey response, anonymous).

Local inhabitants have adopted different strategies in order to cope with the annoyance from the flashing aviation lights. The most extreme strategy is to leave the area, as one interviewee chose to do: "when they put up the test site, I was so annoyed, I knew I would be moving" (Interviewee 3 (male; retired; living in open landscape outside of Østerild; incomer)). As visualised in Fig. 4, most people have adopted less radical measures to cope with the lights on a daily basis: talking to others, the use of blinds to improve sleeping conditions, and joining protest groups were the most frequently mentioned coping strategies.

Others stated that they have moved around furniture inside or outside their house, changed their walking paths, planted trees to shade their houses from the lights, or simply tried to turn away from the flashing lights in their everyday lives, as expressed in the following quotes:

> "If we stay on the spot - if! - then we have to rearrange the terrace so that the flashing lights cannot be seen and plant wide

Table 1
Relationship between frequency of disturbance (winter) and perceived annoyance by obstruction lights as an average over the course of the day (total numbers out of N = 157).

		Perceived annoyance				
		Not at all	A little	Moderate	Pretty much	Very much
Frequency of disturbance	Less than once a week (19)	18	1	10	0	0
	At least once a week (14)	9	3	0	2	0
	Almost daily (39)	19	12	4	4	0
	1–5 times a day (35)	3	6	5	18	3
	More than 5 times a day (50)	1	1	0	19	19

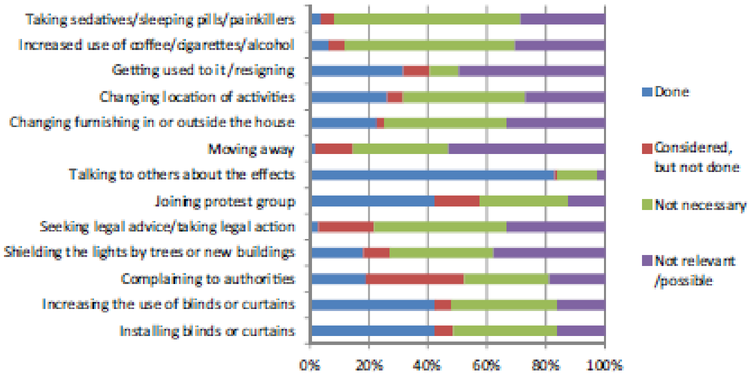

Fig. 4. Frequency of respondents' strategies to cope with annoyance from obstruction lights. Only responses from annoyed respondents are included. N = 111.

fences, which possibly can dim the lights on the ruined view" (survey response, anonymous).

"We have turned our back to it, to put it like that. I mean physically, we have turned our back to that whole corner of our own garden. If I sit down in the garden I would make sure to turn away. A lot of regulation of my own behaviour" (Interviewee 2 (female; employed; living in Østerild plantation; incomer)).

The extent to which the coping strategies have had an effect on the degree of annoyance differed. Our data indicated that, generally speaking, coping strategies have had only a limited effect on levels of perceived annoyance, and that the coping strategies with the relatively greatest effects are physical changes: Changing location of outdoor activities, installing blinds, shielding the light with buildings or trees, and changing the arrangement of furniture. Moreover, social activities such as complaints to authorities and participation in protest groups were generally perceived as having no effect; pharmaceuticals and drugs also seemed to have limited effects.

Apart from the physical limitations on the coping strategies, socio-cultural factors may also provide explanations for the limited effect of coping strategies. In the following, we turn to the issue of sense of place to discuss further explanations for the limited effect of coping strategies.

5.3. *Impacted sense of place as explanation for limited efficiency of coping strategies*

It was evident from the interviewees and survey responses that sense of place and place attachment influence perceived annoyance. Due to the characteristics of the test site area, special attention is paid to the perception of darkness.

5.3.1. *A changed sense of place from obstruction lights*

According to most residents, the most attractive features of the area around the test site are associated with the nature, scenery and quietness (see Fig. 5). These are also the categories that have suffered most from changes over the past years following the establishment of the test site (see Table 2).

According to the descriptive statistics in Table 2, there seemed to be a relation between the annoyance from the flashing lights and the perceived decline in the qualities attached to the area. A similar relation also seemed to exist between the perceived frequency of disturbance of the lights and the decline in qualities of the area. This highlights the importance of exposure to the lights as a critical factor. A small number of the much annoyed citizens admitted to having experienced a positive change in nature qualities, which may be explained by the transformation of the area from forestry to original dune heath as part of the construction of the test site.

The changes in the local qualities were also highlighted by the interviewees. Loss of the place-related values, in part caused by the obstruction lights, was framed by one incomer as a "sell-out of local values" (Interviewee 2 (female; employed; living in Østerild plantation)). In this way, the specific qualities of the area constitute a key reason for choosing to live in the area:

"We [interviewee and husband] were clear that we didn't want to live anywhere near industry, including farming. So the fact that it was a nature area and not farming area, protected by all the different regulations. [...] we were not particularly aware of it, that was just a given that it is protected in every way possible and that nothing at all would ever happen. No industry, no farming, no agriculture, no heavy traffic, no lights" (Interviewee 2 (female; employed; living in Østerild plantation)).

In terms of attachment to the area, the data showed that those who felt that their attachment has become weaker were generally very annoyed by the obstruction lights, whereas those who are not, or those who are only a little annoyed, mostly stated that they have

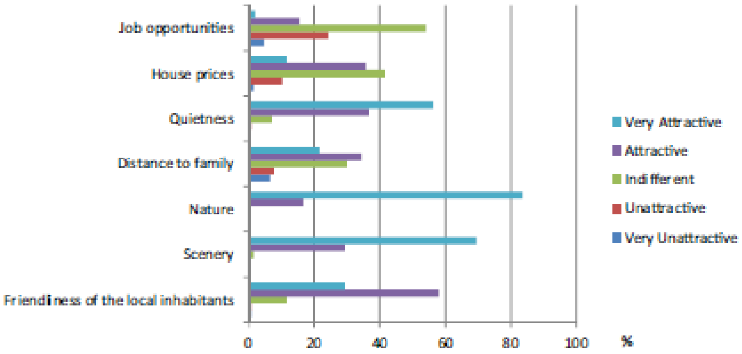

Fig. 5. Respondents' perceptions of qualities of the area. N = 157.

Table 2
Relationship between perceived changes in the quality of the area, attachment to the area and perceived annoyance by obstruction lights as an average over the course of the day.In percentage of 157 responses, numbers in brackets are counts of responses within category.

		Annoyance by obstruction lights		
		Not at all or a little	Moderate	Pretty much or very much
Landscape qualities	Negative change (81)	6%	10%	36%
	No change (51)	31%	2%	3%
	Positive change (19)	10%	1%	2%
Nature qualities	Negative change (69)	5%	8%	31%
	No change (63)	31%	3%	6%
	Positive change (25)	10%	1%	4%
Quietness qualities	Negative change (54)	4%	4%	27%
	No change (100)	41%	8%	15%
	Positive change (3)	2%	0%	0%
Change in attachment to the area	Weaker attachment (13)	1%	1%	16%
	No change (67)	37%	10%	24%
	Stronger attachment (10)	8%	1%	1%

Table 3
Relationship between change in perception of darkness and perceived annoyance by obstruction lights as an average over the course of the day (total numbers out of N = 157).

		Annoyance at obstruction lights from Test Site				
		Not at all	A little	Moderate	Pretty much	Very
Perception of darkness	Much worse (60)	0	4	11	31	14
	Worse (27)	1	9	6	11	0
	No change (51)	39	10	1	1	0
	Better (1)	1	0	0	0	0
	Much better (3)	3	0	0	0	0
	Don't know (7)	6	0	1	0	0

not perceived any change in their attachment to the area, and only a few stated a stronger attachment.

Although the 'sense of place' has supposedly been transformed due to spatial changes induced by the test site and the flashing lights that disturb various outdoor activities, most people stated that they have become used to the lights. Even more so, one interviewee referred to the still unchanged significance and uniqueness of their private property as a haven enclosed by an environment that has been altered by the impact of lights; indeed, this interviewee stated that;

> "although the test site has changed our circumstances, we still consider this as one of the few places which we find beautiful and we are very lucky having our house. It has certainly changed my possibilities outside my own little property, but my house hasn't changed and we can't have anything like this anywhere else" (Interviewee 2 (female; employed; living in Østerild plantation; incomer)).

5.3.2. *Darkness—and the lost Milky Way*

Lastly, there was one essential light-related element of sense of place that many respondents and interviewees cited as a matter of contestation: The darkness in Thy has been widely considered by both newcomers and long-established residents as an exceptional feature that is no longer present due to the obstruction lights.

> "Up here when it gets dark and winter... we have a little street light, otherwise it's pitch-dark [...]. And that's also one of the unique things about the area. [...] There are no disturbing lights" (Interviewee 1 (female; employed; living outside of Østerild; native)).

The place-changing impact of the obstruction lights on the darkness was described by many interviewees who equated the sacrifice of darkness to a loss of uniqueness of the place by often referring to urban areas. The difference between Thy and urban areas invokes a certain societal detachment from real darkness in an increasingly busy everyday life. Darkness exemplifies quietness and standstill in an otherwise frantic world:

"If you prefer to live in a city, you have to get used to lights, but we moved here just because of the loneliness and darkness, to see the stars at night and so on" (Interviewee 2 (female; employed; living in Østerild plantation; incomer)).

"The 'no light thing' is something that we appreciated from the beginning. This true darkness, which you don't find in many places in Denmark; because the country is so small. So even 50 km away from Copenhagen the sky is still affected by the lights of Copenhagen" (Interviewee 4 (male retired; summer house in open landscape outside of Østerild; incomer)).

Moreover, the absence of previously experienced darkness resulted in behavioural changes that have led to frustration and a loss of quality of life:

"When we lived here, we usually took a walk on this road looking at the stars, that's not possible anymore; you could really feel the darkness, and now it's spoiled to take this walk" (Interviewee 3 (female; retired; summer house in open landscape outside of Østerild; incomer)).

"You would not believe it. But on a clear evening, standing outside observing the Milky Way, one cannot directly see the flashes, but still there is a slight rhythmic illumination, which of course destroys one's whole experience of nature, and you are hiding frustrated inside the house" (Interviewee 2 (female; employed; living in Østerild plantation; incomer)).

In turn, the survey data indicated a relation between the perceived change in the darkness and people's annoyance at the obstruction lights (see Table 3): People who felt that their experience of darkness got worse were also the ones who were annoyed by the lights at night and during twilight.

6. Discussion

In this paper, consideration has been given to methodological weaknesses related to the small number of respondents in the survey and biases especially with regard to the sample which was presumably dominated by affected and critical local citizens. Despite this however, the study indicates a range of relations between annoyance, coping strategies and sense of place. Most importantly perhaps, it seems that the variation in annoyance is not only grounded in micro-geographical conditions and changes of behaviour, but also in the sense of place.The empirical findings highlighted darkness as an element of sense of place and an identity-shaping factor for the citizens living in the area.

The findings agree, in some ways, with previous studies concerning citizens' perceptions of aviation obstruction lights on wind turbines [e.g. [11]]. They confirm that citizens' annoyance depends on a range of factors that involve physical circumstances and socio-cultural factors, e.g. nature values and place attachment. The similarities provide an argument for some basic elements of annoyance regarding obstruction lights that are transferable to other contexts, and for an increased conceptual understanding of annoyance. One of these elements is that pollution through obstruction lights should be recognised as a matter of environmental protection, similar to what Lyytimäki et al. [27] argued in terms of traffic lights, and should therefore find wider acknowledgement and practical consideration in EIAs.

The perceived annoyance by obstruction lights is comparable to the perceived annoyance from landscape changes induced by wind turbines. This is interesting, since the EIA of the test site project paid considerable attention to landscape changes and showed limited concern for the impacts of the obstruction lights. This is possibly due to the fact that the Østerild test site is the first of its kind in Denmark, with very tall turbines (i.e. above 150 m). The investigation supports the need for more theoretical clarity of previously applied concepts, such as annoyance and perception. Although the survey was informed by local interviewees' language and description of annoyance, the findings indicate that annoyance is an insufficient terminology to describe the span of perceived impact; indeed, it could be argued that being unable to sleep qualifies as a more significant effect than being annoyed.

Our findings indicate that the impacts of obstruction lights are entangled in and a constitutive element of the perceived changes to the landscape qualities. The individual attachment to the place is not impacted by the obstruction lights and does not seem to be a significant cause of annoyance, but rather provides some stability in people's everyday lives which are affected by the lights, as stated by some interviewees. In contrast, the disrupted sense of place [33,34] in terms of certain qualities constituted through the lived environment and ascribed to the landscape that is pervaded by the flashing lights cannot be effectively overcome by coping strategies. Further, the study points to how the perceived annoyance from obstruction lights may depend on the specific place-based qualities. In the rural area of Østerild, the obstruction lights have an adverse impact on sense of place due to the loss of the unique dark night sky, as well as an adverse impact on the efficiency of coping strategies.

In Denmark, media coverage of the obstruction lights seems to have become a game changer in the planning process, implying that authorities and citizens have paid more attention to obstruction lights since the construction of the test site. The comparability with landscape impacts is also interesting, insofar as several tools have been developed for the assessment of the objective and the more permanent appearance of wind turbines across landscapes (e.g. [18,63,64]); in contrast, tools for assessing the impacts of flashing obstruction lights seem underdeveloped. This, however, also shows an increasing need to consider how concerns and fears turn out in reality and to assess the enduring impacts of operational wind farms that pervade people's lives. Moreover, the findings of this particular case also indicate that the emotional constitution of perceived annoyance may not only be grounded in the actual source of nuisance, but also entangled in related issues, in our case the perception of an unfair planning process, which for some has even made them question their democratic rights in Denmark (Interviewee 2 (female; employed; living in Østerild plantation; incomer)), and which cannot be easily separated from each other. The internalisation of planning-related iniquities may also hint at why coping strategies aimed at mitigating the physical impacts of the obstruction lights are not very effective in allaying people's annoyance. However, it should again be noted that these results are related to a rather extreme case of white flashing high intensity lights in an area previously characterised by darkness, which may look less significant in other cases of commercial wind farms with ordinary lighting. Whilst the unique characteristics of the case limits the transferability (and external validity) of the results to other cases on obstruction lights, the uniqueness of the case in at least two respects – i.e., the extreme darkness of the area, and the unique white, flashing lights of the test site – at the same time has served as a vehicle for raising a previously under-explored issue that needs further exploration in future research. That is, the extreme case has enabled an inquiry into the relationship between sense of place and perceived annoyance over wind farm obstruction lights, which is likely to become a more prevalent issue in the future with ever growing sizes of wind turbines. Indeed, the study serves as a fertile ground for further exploration as well as for future comparative studies between flashing, white lights and permanent, red lights, the impact on sense of place and perceived annoyance, as well as for studies on the potential impact of radar-controlled obstruction lights. Lastly, the study lays the ground for further exploration of the relation between sense of place and place attachment – indeed, with onshore wind turbines often placed in areas marked by depopulation, what will the siting of wind farms in such 'marginalised' 'outskirts' areas do when people feel that their sense of place is being disrupted, whilst they are still feeling the same emotional attachment to the area?

7. Conclusion

The increasing height of wind turbines and requirements on aviation obstruction markings renders impacts from obstruction lights a concern in terms of social acceptance of wind energy. By inquiring into the relation between sense of place and annoyance, this study has contributed to the existing literature through the extreme case of white flashing lights at a test site location in a nature area previously acknowledged for its unique darkness. We have illustrated how perceived annoyance can only be mitigated through coping strategies to a limited extent due to the way in which perceived effects on sense of place are more distinct and due to the internalisation of planning-related iniquities.

Although the results of this unique and extreme case of white flashing lights on light masts in an area renowned for its darkness, as discussed in this study, may not be directly translated to common red lights at turbines, it still accentuates the impacts of obstruction lights as well as the need for further research into this matter. Considering the increasing heights of turbines in future and uncertain regulations, further research could illuminate people's perceptions of alternative options for obstruction lights. Nevertheless, given its similarities to research concerning the annoyance of obstructions lights on wind turbines in Germany and Switzerland, the present study suggests a number of lessons for the wind community and policy makers: Concomitant with very tall wind turbines, obstruction lights can be a significant cause of annoyance in local communities; requirements of obstruction lights may lead to another relevant parameter for location analysis to take potential annoyance into account; impacts from obstruction lights seem to equal visual impacts on landscape and could therefore potentially have similar weight in EIA processes.

Studies regarding perceptions and annoyance of obstruction lights on wind turbines are still rare, and there seems to be potential for research to evaluate how safety lights or high intensity lighting are mitigated or managed across technologies and infrastructures. With this paper, we contribute to the debate on social acceptability of renewables by providing another explanatory nuance of how wind farms and related infrastructures affect local residents and places, and thus inform local responses to wind power.

Acknowledgements

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