Netherlands Enterprise Agency

Aeronautical study into the lighting of wind turbines

A study into the possibility of reducing the visibility of wind turbines from the coast

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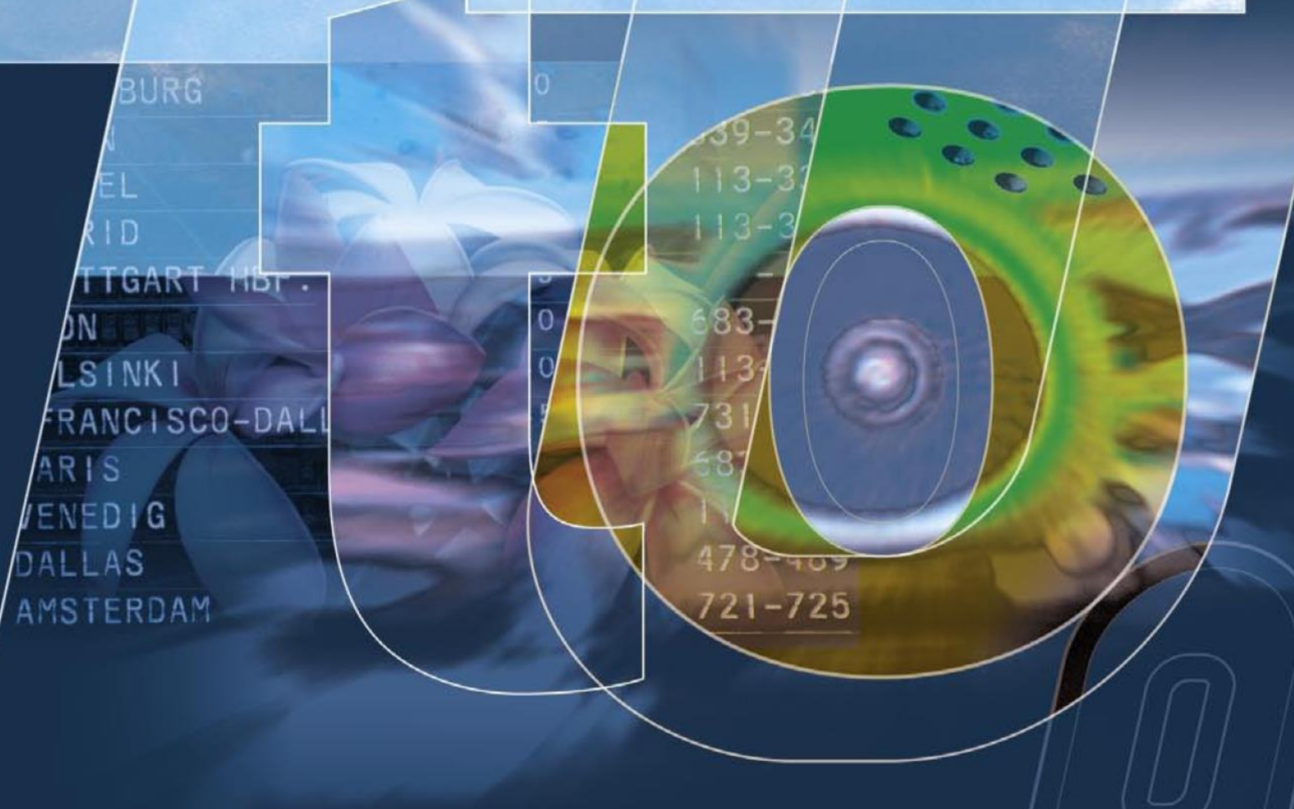

Aeronautical study into the lighting of wind turbines
Aeronautische studie verlichting windturbines

A study into the possibility of reducing the visibility of wind turbines from the coast

Studie naar de mogelijkheden om de zichtbaarheid van windturbines vanaf de kust te reduceren

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Table of Abbreviations

AC	Advisory Circular
AGL	Above Ground Level
AIC	Aeronautical Information Circular
AIP	Aeronautical Information Publication
ATSB	Australian Transportation Safety Board
BWFS	Borssele Wind Farm Site
CAA	Civil Aviation Authority
CAR	Canadian Aviation Regulations
EASA	European Aviation Safety Authority
FAA	Federal Aviation Administration
FIR	Flight Information Region
IALA	International Association of Lighthouse Authorities
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILT	Dutch Civil Aviation Authority
IR	Infra-Red
KNVvL	Royal Netherlands Aeronautical Association
LVNL	Air Traffic Control the Netherlands
NHV	Noordzee Helikopters Vlaanderen
NM	Nautical miles
NVG	Night vision goggles
NWEA	Nederlandse Wind Energie Associatie
RNAV	Area Navigation
RVO	Dutch Enterprise Agency
SAR	Search and Rescue
SLV	Danish civil aviation authority
VAWG	Visual Aid Working Group
VFR	Visual Flight Rules

1 Introduction

The Dutch Government is preparing the development of the following offshore wind farm zones in the North Sea:

- Borssele, approximately 22.2 km off the coast of Zeeland;
- Hollandse Kust (zuid), approximately 18.5 km off the coast of South Holland;
- Hollandse Kust (noord), approximately 18.5 km off the coast of North Holland.

In the development of these wind farm zones, there is a conflict of interest between aviation users and coastal residents. For aviation users, the wind turbines should be well visible for safety reasons. This means that the wind turbines that will be constructed in these areas should, *inter alia*, comply with the aviation safety requirements regarding the lighting and marking as the wind turbines are considered to be an obstacle, in the sense of aviation safety legislation. Residents on the other hand wish keep the horizon clear from obstacles. Considering the distance of the location of the wind farm zones to the Dutch shore, the wind turbines will be well visible from the shore on clear days. The consultation about the *Rijksstructuurvisie Aanvulling Hollandse Kust* in 2015 shows that residents are highly concerned about the visibility of wind turbines[1]. Therefore, it is the government's intention to reduce, to a minimum, the visual impact that these wind turbines have for the communities on land.

To70 conducted an aeronautical study to assess the impact of deviations from international safety standards and national regulations, to present alternative means compliance to ensure the safety of aircraft operations. It assesses the effectiveness of several solutions and recommends mitigating measures when required. This aeronautical study assesses generic solutions and models that could be applied to the above proposed wind farm sites and other, similar[2], offshore sites in the future.

1.1 Objectives

The Dutch Enterprise Agency (RVO) of the Ministry of Economic Affairs tasked To70 to investigate how a safe and compliant lighting system could be installed in these wind farm zones whilst keeping the visual impact of the lighting to a minimum.

This report aims to support the application for approval of specific designs and lighting plans. The suggested solutions from this report require customisation to the actual application for approval by the Dutch Civil Aviation Authority.

1.2 Method

The study was conducted using information about the current airspace structure and use. In addition to the current regulations and guidance material applicable in the Netherlands, the study reviews regulations, guidance material and existing solutions in other locations to seek a feasible solution. The study is the result of a desktop study using available literature and expert judgement. The safety (from an

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[1] 151comments were submitted on the *Rijksstructuurvisie Aanvulling Hollandse Kust* (2015) of which 88 (ca. 59%) concerned the visibility, lighting or nuisance of wind turbines from the seashore.

[2] Similar, in the context of this study, means those offshore wind farm sites where a reduction in light levels is desirable from the point of view of coastal residents.

aviation perspective) of the proposals reviewed will be assessed against in a consistent fashion using an accepted method.

This report is the product of To70's desktop study and several collaborative workshops, held to gain input and reaction from various interested and affected parties. This work was performed as follows:

1.	Kick-off meeting	10-10-2016
2.	Desktop study	October 2016 to February 2017
3.	Initial workshop	15-12-2016
4.	Workshop	01-02-2017
5.	Draft report presented to RVO	02-03-2017
6.	Report submitted to RVO	25-04-2017

Between the date of the kick-off meeting and the report being presented to RVO, several meetings were held with representatives of RVO, Ministry of Economic Affairs, Ministry of Infrastructure and the Environment, Dutch Civil Aviation Authority, Military Aviation Authority and the Dutch Infrastructure and Water Management Agency, Rijkswaterstaat. Attendees were also present from representatives of the energy sector, including the Netherlands Wind Energy Association (NWEA).

1.3 Reading Guide

Chapter 2 consists of a Dutch summary of the report and its conclusions. In Chapters 3 and 4, the situation under study and the related conditions and assumptions are set out. Chapter 5 summarises relevant aviation regulations and guidance material that are in place internationally and in the Netherlands. The experience of other wind farm operators in relation to the impact of the lighting of obstacles, both in the Netherlands and elsewhere is discussed in Chapter 6.

From the above material, Chapter 7 presents an inventory of possible solutions to the issue of light reduction on the wind turbines. The solutions identified are, in Chapter 8, evaluated from the perspective of compliance with aviation regulations, the risk to aviation and the probable perception of community groups. The report ends with conclusions and recommendations in Chapter 9.

This reports uses, in general, metric distances rather than nautical miles (NM). Where nautical miles are used, their metric equivalent is provided in parentheses. For reference, 18.5 kilometres is equal to 10 NM and 12 NM is equal to 22.2 kilometres.

Where this report refers to the Dutch Civil Aviation Authority, ILT, it should be understood that the national Military Aviation Authority, MLA, is also a party that is involved in the development and approval of standards.

2 Nederlandse samenvatting

De Rijksdienst voor Ondernemend Nederland (RVO) heeft To70 gevraagd te onderzoeken hoe de zichtbaarheid van windturbines in geplande windenergiegebieden op zee kan worden geminimaliseerd, met behoud van een acceptabel veiligheidsniveau voor de luchtvaart. De volgende gebieden zijn hiervoor aangewezen:

- Borssele, circa 22.2 km uit de kust van provincie Zeeland;
- Hollandse Kust (zuid), circa 18.5 km uit de kust van provincie Zuid-Holland;
- Hollandse Kust (noord), circa 18.5 km uit de kust van provincie Noord-Holland.

Bij de ontwikkeling van de windparken is er sprake van tegengestelde belangen van bewoners en recreanten aan de kust enerzijds en de luchtvaart anderzijds. De windturbines dienen verlicht en gemarkeerd te worden conform nationale en internationale regels om de veiligheid te garanderen van het luchtvaartverkeer dat in of nabij de windparken vliegt. Als gevolg hiervan, en de afstand van de geplande windmolenparken tot de kust, is het te verwachten dat de windturbines zowel overdag als 's nachts bij helder weer zichtbaar zijn vanaf de kust.

Het is toegestaan af te wijken van de gestelde regels op het gebied van obstakelverlichting en -markering, indien met een aeronautische studie wordt aangetoond dat de luchtvaartveiligheid niet nadelig wordt beïnvloed. Dit rapport verkent daarom generieke oplossingen en modellen voor windturbines op zee, waarbij het windpark Borssele als uitgangspunt is genomen. Deze studie dient als basis voor een aanvraag bij de luchtvaartautoriteiten voor de toepassing van de verkende opties op specifieke locaties. Bij de aanvraag worden de generieke opties aangepast op de specifieke situaties, zodat de luchtvaartautoriteiten deze kunnen beoordelen.

Voor deze studie zijn de relevante regelgeving en richtlijnen geanalyseerd ten aanzien van obstakelverlichting en -markering. Ook is onderzocht welke opties in andere landen worden toegepast, en welke categorieën van luchtvaart in en nabij de windparken actief zijn. Vervolgens is een risicoanalyse uitgevoerd aan de hand van het 5x5 risicomatrix, een standaard toegepaste methode in de luchtvaart.

Deze aeronautische studie verkent de volgende opties om de zichtbaarheid van windturbines zo veel mogelijk te beperken.

- Minder windturbines verlichten;
- Een lagere lichtintensiteit toepassen;
- Een camouflagepatroon of gebroken wit of grijs aanbrengen op de mast en rotorbladen van de windturbines;
- Lampen afschermen;
- Detectiesystemen, en
- Infrarood systemen.

Onderstaande paragrafen presenteren de belangrijkste conclusies van de aeronautische studie.

Minder windturbines verlichten

Voor het verminderen van het aantal lampen in het windpark zijn de volgende opties verkend:

1. Knipperende contourverlichting (met maximaal 900 meter afstand tussen lampen), in lijn met het Informatieblad van ILT.
2. Vastbrandende lampen met een 1200 meter gridconfiguratie, in lijn met FAA Advisory Circular.
3. Een combinatie van 1 en 2, waarbij vastbrandende contourverlichting wordt toegepast in de volgende configuraties:
    - Variatie 1: Contourverlichting van alle percelen
    - Variatie 2: Contourverlichting van het hele windpark
    - Variatie 3: Contourverlichting van de percelen ten noorden en ten zuiden van de doorkruisende scheepvaartroute;
    - Variatie 4: Contourverlichting van kavel I & II, and kavel III, IV & V.

Het toepassen van knipperende contourverlichting, waarbij alleen de windturbines op de randen van het park worden verlicht (waarbij de maximale horizontale afstand tussen twee windturbines voorzien van obstakellichten minder dan 900 meter bedraagt) is reeds toegestaan conform ILT Informatieblad, evenals het toepassen van een gridconfiguratie met een afstand van 1200 meter tussen de lampen (optie 1 en 2).

Het toepassen van vastbrandende contourverlichting wordt als een haalbare optie gezien. Hiermee kan het aantal lampen met 27 tot 73 % worden gereduceerd ten opzichte van een situatie waarbij alle windturbines verlicht worden. Hierbij wordt uitgegaan van een implementatie van vastbrandende contourverlichting, waarbij de afstand tussen de lampen op de horizon gezien (vanuit de cockpit) maximaal 900 meter is. Hierbij wordt beargumenteerd dat de maximale afstand van 900 meter tussen de lampen bij toepassing van contourverlichting, zoals voorgeschreven in het informatieblad, op de horizon gezien gegarandeerd wordt, ook als de lampen zelf op grotere afstand van elkaar staan.

Op basis van de risicoanalyse wordt geconstateerd dat de volgende oplossing het meest wenselijk is:

1. De implementatie van vastbrandende in plaats van knipperende contourverlichting, waarbij de exacte configuratie afhankelijk is van de keuze van de ontwikkelaar van het windpark (d.w.z. contourverlichting per perceel, site of zone). Hierbij dient te worden opgemerkt dat de afstand tussen de lampen tot 1200 meter mag zijn, maar dat de afstand op de horizon gezien tussen lampen maximaal 900 meter is.
2. Om te garanderen dat de afstand tussen lampen op de horizon maximaal 900 is, kan het zijn dat het nodig is tevens één of meerdere windturbines te verlichting binnen de contour.
3. Elke windturbine met een ashoogte groter dan 150 meter, dient tevens te worden uitgerust met lampen op de mast.

De volgende mitigerende maatregelen worden voorgesteld als onderdeel van vastbrandende contourverlichting:

- Een protocol dient te voorzien in de optie het gehele windpark op zeer korte termijn te verlichten wanneer de kustwacht met een helikopter door/ in het betreffende windpark een vlucht moet uitvoeren. Alle windturbines dienen daarom sowieso voorzien te worden van rode vastbrandenden lampen op de mast en de rotor.

- Alle windturbines binnen een straal van 5 NM van een helikopterplatform dienen verlicht te worden indien nachtoperatie plaats vindt.
- Windparken dienen nauwkeuriger aangemerkt te worden op aeronautische kaarten.
- Informatiemateriaal dient ontwikkeld te worden voor zowel de kleine luchtvaart (general aviation) als commerciële luchtvaart en overige luchtruimgebruikers die van het luchtruim gebruik maken nabij de windparken.
- De ontwikkeling van data voor een database met obstakels is nodig. Een Restricted Airspace zone om ieder windpark is aan te bevelen om het bewustzijn van piloten te verhogen.
- Militaire straalvliegtuigen dienen de windparken te vermijden onder 1200 ft, binnen een straal van 5 NM.
- Contourverlichting kan enkel gecombineerd worden met een reductie van lichtintensiteit (conform ILT Informatieblad) indien de zichtbaarheid van de contour gegarandeerd is met behulp van een lichtplan.

Lagere lichtintensiteit
Het reduceren van de lichtintensiteit, conform ILT Informatieblad, is toegestaan. Een verdere verlaging van de lichtintensiteit, naar voorbeeld van het Verenigd Koninkrijk, wordt niet gezien als een haalbare oplossing, omdat deze niet voldoende onderbouwd is. Aanvullend onderzoek is nodig voordat deze optie kan worden geaccepteerd. Het combineren van een lagere lichtintensiteit conform ILT Informatieblad en contourverlichting (op basis van de interpretatie van bovengenoemde regel met maximaal 900 meter tussen de lampen op de horizon), is enkel mogelijk als de lampen ook voldoende zichtbaar zijn.

Toepassing van camouflagepatroon of gebroken wit of grijs op de mast en rotorbladen van de windturbines
Het toepassen van een camouflagepatroon of kleuren die niet onderschreven worden door ILT Informatieblad, zijn nog onvoldoende onderbouwd. Dit wordt echter wel gezien als een kansrijke maatregel, maar nader onderzoek is nodig om te bepalen welke patronen duidelijk zichtbaar zijn op een afstand van 5 tot 8 km. Hierbij dient te worden opgemerkt dat camouflage nog in geen enkel land is toegestaan.

Afscherming van lampen
Het afschermen van de lampen, zodat deze vanaf de kust niet of nauwelijks zichtbaar zijn, wordt niet gezien als een haalbare oplossing. ILT merkt op in het Informatieblad dat afscherming onder het horizontale vlak weinig effect heeft op het waarnemen van het obstakellicht op een grote afstand.

Detectiesystemen
Met behulp van een detectiesysteem kunnen lampen automatisch aangezet worden wanneer een vliegtuig of helikopter in de buurt komt van het windpark. Op basis van deze aeronautische studie kan nog geen uitspraak gedaan worden van de haalbaarheid van de toepassing in Nederland. Op basis van de beschikbare informatie wordt geconstateerd dat de technologie mogelijk voldoende volwassen is. Aanvullend onderzoek wordt aanbevolen, indien detectiesystemen overwogen worden.

Infrarood systemen

De toepassing van infraroodlampen wordt gezien als een optie die enkel kan worden toegepast als aanvulling op overige opties. Niet alle luchtruimgebruikers maken namelijk gebruik van infrarood-technologie. Dit geldt met name voor de Kustwacht, die reddingsoperaties moet kunnen uitvoeren in en nabij de windparken.

3 Situation under study

The study examines the feasibility of reducing the visibility from the coast of the lighting required on wind turbines planned to be constructed in three large wind farm zones in the North Sea off the coast of three Dutch provinces; Zeeland, South Holland and North Holland. Specifically, the study reviews the possible reduction in the number and position of lamps and lighting levels and, therefore, its perceived nuisance from the sea shore. This chapter describes the current situation and the issues under consideration.

The three wind farm zones planned are located as described below. No wind farm boundary is less than 18.5 km from the coast. The wind farm zones are located in areas of the North Sea where helicopter operations to and from oil and gas platforms and rigs and support vessels are common. In addition, other aviation users make use of the airspace above the planned wind farm zones. These users include military flights, coastguard operations and general aviation flights. The scope of the work is such that commercial operations into and out of airports such in Amsterdam and Rotterdam are excluded. This is due to the fact that these aeroplanes fly sufficiently high over the North Sea so that the wind turbines pose no hazard to them. The same, by extension, applies for en-route traffic flying on Air Traffic Service routes above the North Sea.

The reduction in lighting levels that is to be studied specifically relates to:

- The application of continuous illuminated light on all turbines or dimmed to 30 or 10% of the light intensity;
- A derogation from the current national policy so that the lights halfway up the wind turbines might not have to be installed;
- A derogation from the current national policy by allowing the use of a continuous illuminated light only at the corner of groups of wind turbines or at the corner points of the wind farm sites;
- A derogation from the current national policy whereby the maximum distance between illuminated turbines in a group of wind turbines may exceed 900 Meters, and
- To what extent can the wind farm operators deviate from the current national policy with regard to the application of the colour white (RAL9001, RAL 9003, RAL 9010 and RAL 9016) that is required.

3.1 North Sea wind farm zones

The lighting of wind turbines at three wind wind farm zones in the North Sea, from north to south, Hollandse Kust (noord), Hollandse Kust (zuid) and Borssele, is under study. The location of the three wind farm zones is shown below.

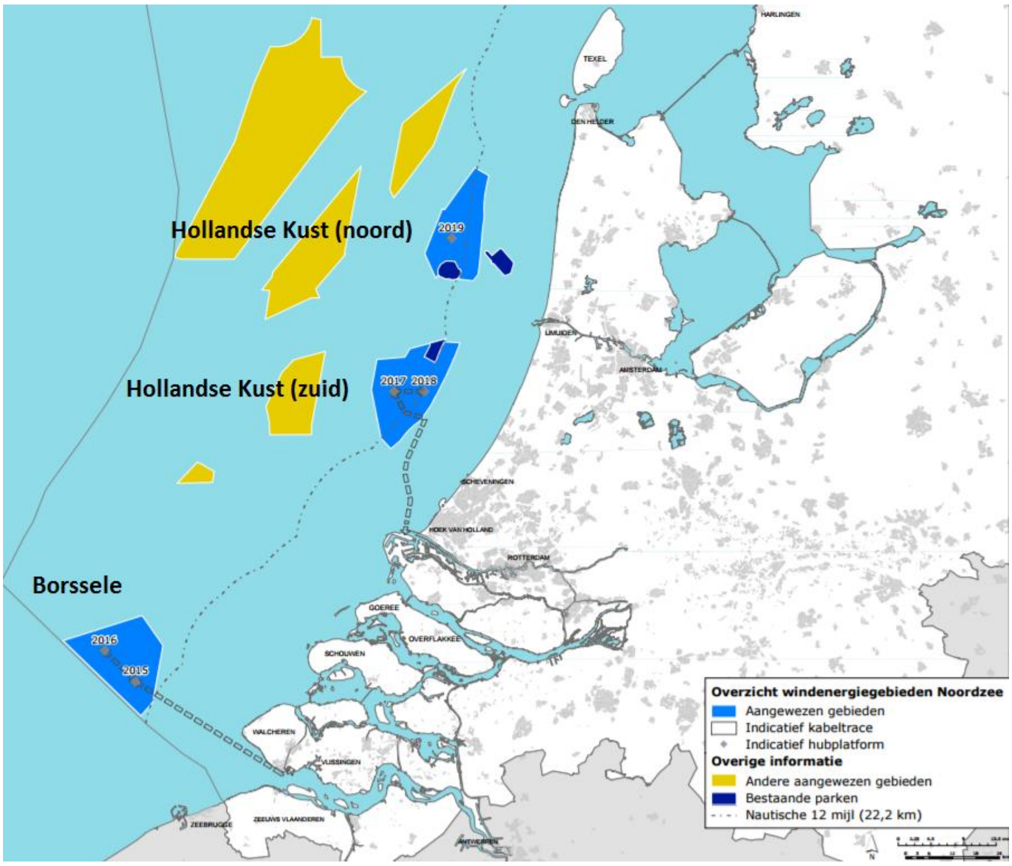

Figure 1: Location of the three offshore wind farm zones (Source: Noordzeeloket)

The three wind farm zones have, according to the regulations that define them, the following basic characteristics.

Name	Closest distance to land	Size	Composition of wind farm	Output sites
Borssele	22.2 km off the coast of Zeeland	344 km^2	five sites, 3x 350 MW,1x 330 MW plus a fifth small site for innovation of ca. 20 MW	1400 MW
Hollandse Kust (zuid)	18.5 km off the coast of South Holland	ca. 320 km^2	four sites, 350 MW each and existing wind farm Luchterduinen (129 MW)	1400 MW
Hollandse Kust (noord)	18.5 km off the coast of North Holland	ca. 290 km^2	one site of 700 MW, and existing wind farm Prinses Amalia (120 MW)	700 MW

Table 1: Basic characteristics of the three wind farm zones (Source: Rijksstructuurvisie Windenergie op Zee Aanvulling gebied Hollandse Kust, December 2016)

This study has chosen a representative sample type wind turbine to allow calculations and assessments to be made. In the report, the 8MW Vestas V164 wind turbine. Its basic dimensions are shown in Figure 2 below. Each of the three wind farm zones will be populated with wind turbines that have a power output of between 4 and 10 MW. It should be noted that there is no upper power limit defined for Hollandse Kust (noord). Typical rotor diameters for the wind turbines that are likely to be used are between 160 and 184 metres.

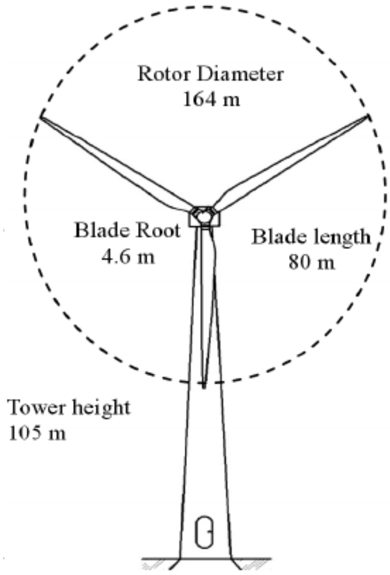

Figure 2: Dimensions of a Vestas V164 wind turbine

In addition to the basic dimensions of the sample wind turbine shown above, it should be noted that the Site Decision includes a requirement for the lowest level of the blade's tip to be at least 25 metres above sea level (Mean Sea Level). This means that the typical highest level of wind turbine tips will be between 185 and 209 metres above Mean Sea Level. It should be noted that current regulations limit wind turbines to a maximum height of 251 metres above Main Sea Level.

It should be noted that the use of this wind turbine is in no way an endorsement of the wind turbine, nor is it intended to imply that the type will be used by any party in populating the offshore wind farm zones.

3.2 Aviation users

Several different aviation users have been identified as likely to operate at low level (see below for an introduction into the meaning of 'low level', as used in this study) in the southern North Sea. This list of operators includes both operators that are involved in oil and gas work and those that are not; commercial and private operators and fixed-wing and rotorcraft operators. These operations are summarised in the following table. A detailed overview of the operations that are conducted by these users is reproduced in Appendix C. Data on the number of flights, as reported by Air Traffic Control the Netherlands (LVNL) follows in the text below Table 2.

Operator		**Operations possible close to wind farm zones**	**Operations possible inside wind farm zones**	**Typical speeds**	**Typical en-route altitudes**
Helicopter operations	Oil and gas support	YES	NO[3]	130 – 150 kts	1500 - 3000 ft[4]
	Coastguard (Search and Rescue, SAR)	YES	YES	70 – 150 kts	50 – 2000 ft
	Police (for Rijkswaterstaat)	NO	NO	70 – 150 kts	500 ft
Fixed wing operations	Coastguard	NO	NO	170 – 190 kts	100 – 1000 ft
	Military	N/R	NO	>= 250 kts	> 1200 ft
	General Aviation, crossing North Sea	NO	NO	95 – 150 kts	1000 – 5500 ft VFR 5500 – 12000 ft IFR

Table 2: Summary of operations conducted in the North Sea

[3] On a regular base helicopter operations for oil and gas support does not take place inside wind farm zones, unless an oil/ gas platforms and rigs are located within the wind farm zones. In these cases, a separate risk assessment/ accessibility study shall take place for this specific location.

[4] Typical en-route altitude does not consider the approach and departure to and from platforms.

LVNL provided information for the period January 2012 to September 2016 on both Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) flights conducted at low-level above the North Sea in the Amsterdam Flight Information Region (FIR), to provide insight into the number of flights and category of aviation taking place above the North Sea. The data was not wholly complete in terms of altitudes, distance operated from the coast, etc. However, several general trends were noted:

- Dutch offshore helicopter operations have decreased slowly since 2012 from about 2600 flights a month to around 2000 flights a month in the first nine months of 2016.;
- No offshore helicopter operations took place to the north of the Netherlands since the start of 2012 above the North Sea by German companies operating from Dutch / German border in the province of Groningen. Since 2013, the trend has steadily increased to a point whereby about 300 flights a month were conducted in the first six months of 2016;
- The number of flights by the Coastguard is stable in the period 2012 to 2016 at around 200 flights per month (the LVNL data does not distinguish between fixed wing and helicopter flights);
- Helicopter flights operated by the police in the North Sea are also stable over the period reported; usually less than 10 per month;
- Military operations also display a stable trend at around 200 flights a month above the North Sea. LVNL reported a group of flights as 'other'. No data was available on the types of aircraft flown. These are understood to be military flights; mainly in the North Sea to the north of the country. The trend here for the period 2012 – 2016 is steady, with a slight decline; from 1100 flights a month to about 900, and
- The trend for general aviation, VFR flights, was stable over the period; 500 to 600 flights per month.

The lack of detail in the data obtained precludes an in-depth analysis of the frequency of flights conducted by the various aviation users in the areas of the North Sea where the wind farm sites will be located. As a result, the qualitative risk assessments are more conservative than they might be. For example, as shipping is permitted in the wind farm sites, it is assumed that search and rescue flights may operate there. The likely frequency of such flights is unknown. Likewise, the number of VFR-flights and the altitude at which they operate is not known. It is, conservatively, assumed that such traffic will seek to operate above the wind farm sites.

The data in Table 2 above excludes the take-off and landing phase for helicopters to oil rigs and gas platforms. Considering the need for flight crew to have a high level of situational awareness during approach and departure procedures, it is assumed that all wind turbines within a range of 5 NM of a helideck will be illuminated when night operations take place . The figure of 5 NM is derived from the current 5 NM radius of the HPZs so as to allow for approaches or departures.

Apart from military fast-jet traffic, the general aviation community is the only aviation user that operates over the North Sea with single-engine aircraft. By definition, a single-engine cannot continue flight following an engine failure and will need, when above the North Sea, to ditch in the water. Whilst a geometric calculation can be made for the distance that a single-engine aircraft can glide based on an ideal glide ratio, altitude and speed, in real life such calculations have proved to be unrealistic. Cessna, for their C152 and C172 model aeroplanes, states that a realistic glide distance at best glide speed is 1.5 NM

(2.8 km) per 1,000 feet. That is to say that at 2,500 feet altitude, the aeroplane will glide for 3.75 NM (7 km) after engine failure. At 5,500 feet, the Class A airspace ceiling above the North Sea, this figure rises to 8.25 NM (15.3 km). The relevance of this data is that the centre point of the three wind farm zones can be further away from the wind farm's edge than 8.35 NM or 14.9 kilometres. From this distance, the maximum altitude above the wind farm zones, when operating under VFR would not always allow a single-engine aircraft to glide clear of the wind farm.

In the context of this study, low level means at or below about 6,000 feet. This discriminator is intended to exclude those airline flights descending into or climbing out from either Schiphol Airport or Rotterdam Airport. To confirm that these flights could be excluded, To70 has reviewed ADS-B for flights[5] above the North Sea along a line from, approximately, the north of the Hollandse Kust (noord) wind farm zone to the south of the Borssele wind farm zone. The data shows that almost all traffic for these two airports is above at least 13,000 feet altitude on passing the wind farm zones addressed in this study. Detailed information is contained in Appendix C.

[5] 5,000 flights for Schiphol and 2,500 flights for Rotterdam in the period between 1 January 2016 to 31 October 2016 were used for the production of the heat maps.

4 Conditions and assumptions

Prior to commencing the study, To70 established several condition and assumptions that would apply to the study. They are divided into two groups:

- Relating to the wind farm / wind turbine, and
- Aviation issues.

4.1 North Sea wind farm zones / wind turbines

- There are specific regulations and policies regarding the marking and lighting of wind turbines contained in:
  - Water Decree article 6.16h,
  - Wind farm site Decisions Borssele I-V, adopted on 8 April 2016, refer to the Water Decree, and,
  - Wind Farm Site Decisions Hollandse Kust (zuid) I and II adopted on 16 December 2016 prescribes in regulation 4.6 the use of steady and dimmable red lamps for wind turbines, as allowed in the *Infomatieblad*.
- In accordance with this regulatory basis and the wishes of the coastal communities not to have flashing lamps installed on wind turbines, only steady lamps are considered in this study.

4.2 Aviation

- The information on airspace use.
- It is not the primary purpose of this study to curtail any aviation activity that is currently legally conducted above the North Sea. Restriction, if required, will be kept to a minimum and only be proposed in the interests of flight safety and/or the safety of the wind farm.

5 Regulations and related guidance material

The regulations and guidance material that are primarily applicable to the study are those that relate to aviation safety and the marking and lighting of obstacles higher than 150 metres. Where applicable, draft material has also been reviewed.

This section of the report commences with international regulations, starting with International Civil Aviation Organisation (ICAO). Following this, the current Dutch requirements and guidance material are reviewed. Relevant regulations and guidance from other countries is also reviewed in this section.

5.1 International regulations

Regulations related to protection of aircraft from obstacles include material on their location and their marking & lighting. Outside the immediate vicinity of an aerodrome (i.e. beyond the so-called obstacles surfaces), the regulations primarily address the marking and lighting of obstacles. The main sources of international legislation are:

- ICAO Annex 14, Volumes I & II – design requirements for aerodromes, including obstacle marking and lighting;
- European Aviation Safety Authority (EASA) CS ADR – Annex 14, as transposed into the European Union's legal system via EASA, and
- EASA SERA – the rules of the air as in force in the Netherlands, again via EASA.

The EASA requirements for aerodromes, EASA CS ADR, only cover airports (equivalent to Annex 14 Volume I) and not heliports (as contained in Annex 14, Volume II). For the purpose of lighting obstacles outside an obstacle surface, Annex 14, Volume I contains all the necessary requirements. These are reproduced in Appendix D to this report. The other requirements are not described in detail here.

5.2 National regulations

As the EASA documents are applicable in the Netherlands, no further aviation regulations would be expected to apply in the Netherlands. However, several national regulations have been developed in relation to the building of offshore wind farm zones. These are summarised as follows:

- The Water Decree, contains several relevant regulations, including:
    - The standards for the marking and lighting of wind turbines that are contained in the recommendation 0-139 of International Association of Lighthouse Authorities (IALA) and the UK Civil Aviation Authority guidelines CAP 764 are applicable.
    - A wind farm shall have control systems, warning systems and operating systems, including a back-up mechanism, that can be operated from the site as well as from the shore.
- The Wind Farm Site Decisions I & II Hollandse Kust (zuid) included specific regulations that are applicable to aviation. These include:
    - Steady, red, lighting shall be used on the wind turbine nacelles, and
    - Under certain visibility conditions the lamps shall be dimmed to either 30% or 10% of their capacity during twilight and the night.

Building on the above regulations, a document has been produced by the Dutch Civil Aviation Authority (ILT) regarding the marking and lighting of wind turbines that are 150 metres tall or greater. This document (see below), entitled in Dutch, *Informatieblad Aanduiding Offshore windturbines en offshore windparken in relatie tot luchtvaartveiligheid* is not primary legislation but it does present the ILT's position and its interpretation of the ICAO and EASA material.

The national military regulations were not reviewed as part of this study.

5.3 Guidance material – Netherlands

The ILT's position and interpretation of the ICAO and EASA material regarding the marking and lighting of wind turbines that are 150 metres tall or greater is contained in a document, entitled in Dutch, *Informatieblad Aanduiding Offshore windturbines en offshore windparken in relatie tot luchtvaartveiligheid*. The version used in this study was version 3.0, dated 30 September 2016.

The *informatieblad* contains a detailed description of how wind turbines – as single elements or a part of a wind farm – should be marked and lit from the point of view of aviation safety. The following points[6] are of relevance to the current study:

- The proposal for the marking and lighting of the wind turbines shall be submitted to the Ministry of Infrastructure and the Environment.
- The boundary between nautical and aeronautical marking of a wind turbine is at a point 30 metres above mean sea level.
- All of the structure above the 30 metre point shall be painted white (see 3.2 & Appendix).
- The *informatieblad* defines a pattern for the lighting of wind turbines within a wind farm, (see Appendix III).
- The position of lights on a wind turbine are specified. One set on top of the nacelle and another set of lights on the tower, no further below the upper lights than 52 metres (see 5 and Appendix IV).
- The conditions required for the exemption to the need to light the wind turbine in 5.c.i, ii, iii & iv are not met in the case of the three offshore wind farm zones under consideration in this study. The use of an aeronautical study to justify not lighting the wind turbine is raised in 5.c.v. This is a reference to the recommendation in Annex 14 Volume I, 4.3.2.
- The upper lighting may consist of a steady red light or a flashing red light (see the *Informatieblad*).
- Lighting should be visible in all directions of flight.
- Within the limits set out in Appendix V of the *Informatieblad*, the lights do not have to shine below the horizon. This is to reduce the risk of confusion to seafarers. This requirement has a footnote[7] attached to it that reads: *"Hierin is gedefinieerd onder welke hoeken, zowel verticaal als horizontaal, een bepaald type obstakellicht licht moet uitstralen. Omdat deze voorwaarden in een aantal gevallen ook bepalen dat het licht tot enkele graden onder het horizontale vlak zichtbaar moet zijn zullen obstakellichten niet in alle gevallen onder het horizontale vlak afgeschermd kunnen worden. Daarnaast wijst de praktijk uit dat afscherming onder het horizontale vlak weinig effect heeft op het waarnemen van het obstakellicht op lange afstand. Om de beleving van lichthinder te minimaliseren worden in dit informatieblad andere mogelijkheden geboden waaronder het*

[6] References here are to the *informatieblad* and not to texts in this report.

[7] The footnote refers at the time of this report being prepared, in error, to Appendix VII; it should be a reference to Appendix V.

toepassen van regeling van de lichtintensiteit en het toepassen van vastbrandende obstakellichten buiten de daglichtperiode."

- Where lights flash within a wind farm, they shall be synchronized to operate together.
- The reduction in intensity at dusk and at night mentioned in the footnote is set out in 6.1 and 6.2. In summary:
  - Visibility >5,000 metres: reduce intensity to 30%
  - Visibility >10,000 metres: reduce intensity to 10%
  - Visibility measuring equipment unserviceable; no reduction possible.
- Paragraph 9 of the *Informatieblad* permits alternative approaches to be proposed via an aeronautical study. An equivalent level of safety shall be assured. The proposal approach shall be submitted to the ILT.
- The definition of aeronautical study includes several important elements:
  - It shall be risk analysis;
  - It shall, at least, address aviation safety considering the local air traffic, airspace use, air traffic requirements, airspeeds, altitude and the direction from where the wind farm might be approached.
  - Expected weather conditions, including low cloud base and low visibility shall be considered. The worst weather that the airspace requirements permit operations in shall be considered.
- Day and night are not defined by the angle of the sun to the horizon, as per the usual aviation definition, but by light conditions; greater or less than 500 cd/m^2.
- Appendix V contains a summary of three tables from ICAO Annex 14 Volume I; Tables 6-1, 6-2 & 6-3.

5.4 Regulatory and guidance material – other countries and organisations

Wind farm zones at sea are not unique to the Netherlands. Other countries, including some of those around the North Sea, also have wind farm zones at sea. As part of the study, regulations and guidance material that has led to solutions relating to the visual impact of the lighting on wind turbines has been reviewed. It is of note that not all of the regulatory and guidance material differentiates between onshore and offshore wind farm sites. The material below was developed as either a generic requirement or specially addresses offshore facilities. The main sources identified include:

- EASA Guidance Material and Alternative Means of Compliance, and
- Policy of aviation authorities in other countries:
  - Australia,
  - Civil Aviation Safety Authority,
  - Canada, Transport Canada
  - Denmark, *Statens Luftfartsvæsen*,
  - Finland, Finnish Transport Safety Agency
  - Germany, *Luftfahrt Bundesambt*;
  - Norway, *Luftfartstilsynet*;
  - Sweden, *Luftfartsverket*;
  - UK, Civil Aviation Authority, and
  - USA, Federal Aviation Administration.

The table below summarises the information from each State that was publicly available from aviation authorities and wind farm operators in those States regarding the marking of turbines that are greater in height than 150 metres. Further notes on each national policy follows the table.

It is noted that many States have differing requirements for lighting wind turbines dependent on the height of the turbine. In general, for wind turbines up to a height of 150 metres above the surface, aviation obstacle lighting does not have to be flashing. For turbines that are greater than 150 metres high, flashing lamps are more commonly required.

Aviation authority	Distance between markings	Lights (red or white)	Lights (steady or flashing)	Reduction permitted	Colour of tower & rotor blades
ICAO	Up to 900 m	Red	Either	Not mentioned	White
AUS *	Up to 900 m	Not specified	Not specified	Not specified	Not specified
BE	Up to 900 m	Red	Steady	Yes	-
CA	Up to 900 m	2 x red at top, tower lit	Flashing	No	White
DE	Permitted, distance not reported	2 x red & 4 x white at top, 2 x white on tower	Flashing	Yes	White, orange tips
DK *	Up to 900 m	White (day) & red (night) on outer towers Red on inner towers	Flashing on outer towers Steady on inner towers	Not specified	Light colour[8]
FI	Very different set-up	2 x red at top	Steady	Yes (to 30% & 10%)	White
NL	Up to 900 m	Red at top and on tower	Steady	Yes (to 30% & 10%)	One of four shades of white and one shade of light grey
SE	Not permitted	White on outer towers Red on inner towers	White flashing Red steady	No	-
UK	Up to 900 m	Red at top and on tower	Steady	To 10% with vis > 5km	White
US	No gap > 1.6 km	2 x red at top	Flashing	No	White or light grey

* = Requirement is stated as being 'as per ICAO'.

Table 3: Requirements of States for lighting wind turbines

[8] 'Light' as in 'not dark'

5.4.1 Canada

Regulations related to marking and lighting of wind turbines are stated in the Canadian Aviation Regulations (CARs), Part VI General Operating and Flight Rules, Standard 621 Obstruction Marking and Lighting, effective 01-03-2016. For wind turbines exceeding 150 m, the following regulations apply:

- Marking requirements:
  - For a single wind turbine and wind turbines of a wind farm, having a solid silhouette, the rotor blades, nacelle and upper 2/3 of the supporting tower are painted a white or an off-white colour;
  - A wind turbine having a lattice-work support tower has the tower painted in bands of orange and white as for skeletal structures.
- Lighting requirements, as illustrated in figure 5.1
  - Two CL-864 lights are installed on the nacelle. Only one light operates at a time, the second light serving as a backup in case of failure of the operating light.
  - Three CL-810 lights are installed for an intermediate level at half the nacelle height and configured to flash at the same rate as the light on the nacelle
  - The lights are installed in such a manner as to provide an unobstructed view for aircraft approaching from any direction.

It is of note that Transport Canada has developed detailed requirements for the use of detection equipment that allow the lighting to be illuminated only when aircraft are detected near the turbines. Such systems will actively detect an aircraft and will not rely solely on aircraft equipment (e.g. transponders). In addition to the timely illumination of the lamps, an audio signal will be transmitted. Built-in test requirements also exist. See CAR, Part VI, Standard 621, Chapter 15 for further details.

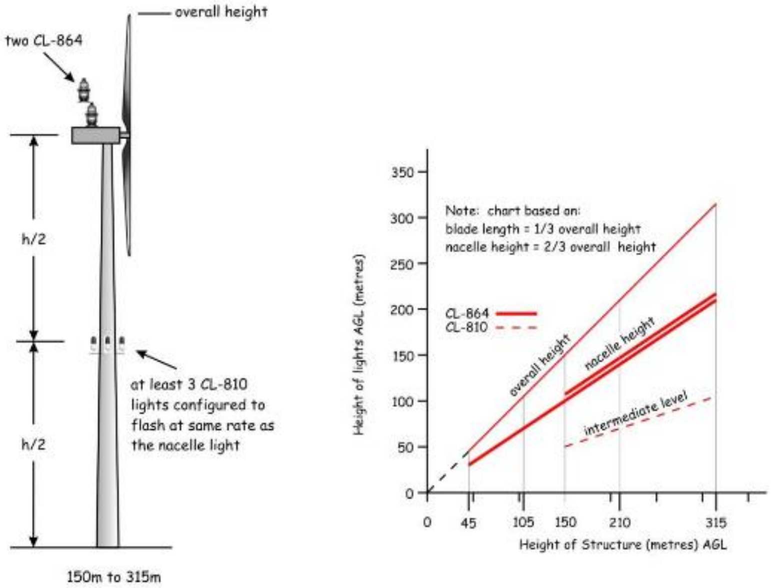

Figure 3: Lighting wind turbines, heights 150m to 315m (source Canadian Standard 621)

5.4.2 Denmark

The Danish aviation authorities, in conjunction with the Danish Air Force, agreed on an obstacle marking policy related to wind turbines. In Denmark, the present marking consists of two red and flashing lamps on top of the nacelle [9]. This is accepted for obstacles of heights up to 150m. If the blade tip in top position is lower than 100m no particular markings are required. The blades so far have not been required to be marked at all. In ongoing discussions requests have been voiced in favour of a paint scheme similar or equal to that of the German pattern. Wind turbines exceeding 150 meters shall be marked as per ICAO requirements. The use of flashing lamps is not addressed in this study, as per the assumptions listed in Chapter 5 of this report.

5.4.3 Finland

The boundary markings that Finland permits differ greatly from that permitted in other States. The requirements are summarised in two diagrams below.

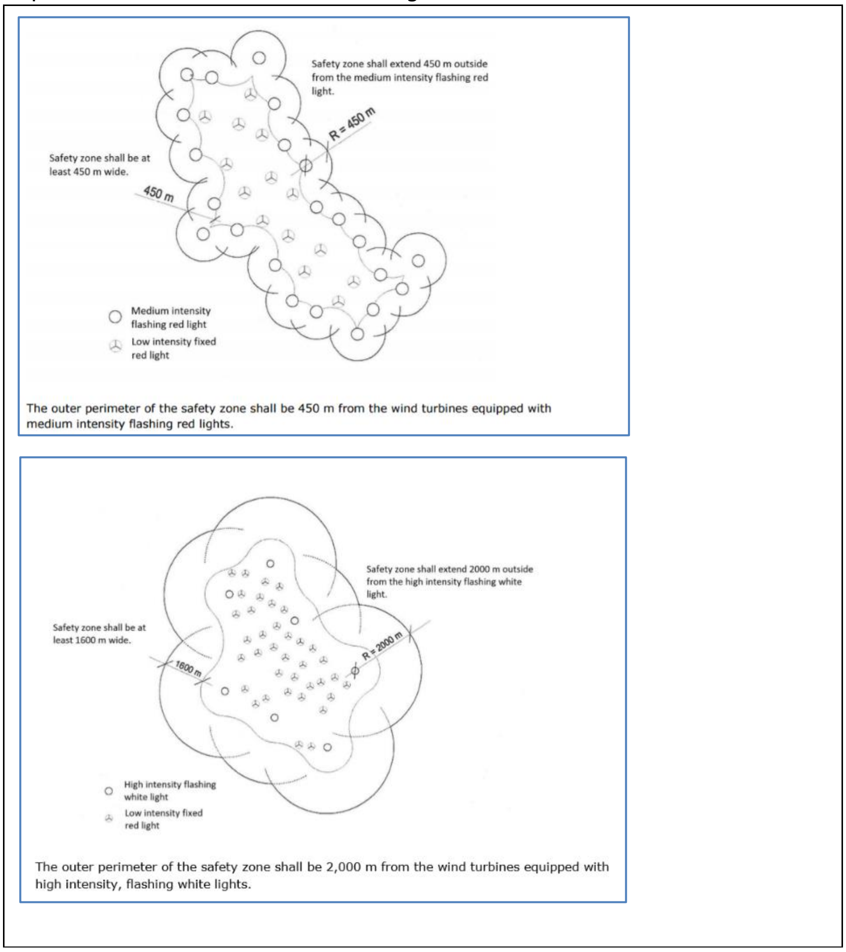

Figure 4: Model of contour lighting from Finnish Transport Safety Agency

The Finnish requirements are more stringent than that permitted by the ILT's *Informatieblad*.

[9] Memo 979 from CAA Denmark

5.4.4 Germany

In Germany, the legislation for marking and lighting of obstacles is regulated in the general administrative regulation, effective 24th of April 2007. These regulations are issued by *Deutsche Flugsicherung* (authority for air traffic control in Germany). The German guidelines are shown in Figure 5.

Height	Daytime marking	Night time marking
< 100 m	No marking	No marking
100 m to 150 m	2 x lamps medium intensity type A (following approval) + color ring on the tower *or* 2 x 6 m red stripes on the rotor blade tips	2 x lamps medium intensity type B
> 150 m	1 x 6 m red stripes around the rotor blade tips + 2 x lamps medium intensity type A + color ring on the tower 40 ±5 m high + red stripes on the nacelle *or* 2 x 6 red stripes around the rotor blade tips + color ring 40 ±5 m high + red stripe on the nacelle	2 x lamps medium intensity type B *and* 4 x lamps low intensity type A on the tower, 3 m below the rotor blade tip, then every 45 m, but not in the bottommost 45 m

Explanation: Type A: White light (daytime marking)
Type B: Red light (night time marking)
Height: Total height up to rotor blade tip

Figure 5: German guidelines (source: Obstacle lights for day and night, NORDEX)

In addition, the following guidelines apply:

- Beyond airports, the height at which a marking is needed depends on the residential area. Cities from 150 metres, sparsely populated areas from 100 metres;
- Day time marking is red/white marking or white light, 20,000 cd;
- Night time marking is red light, 2,000 cd or 100 cd
- For night time marking, two lights per wind turbine must be operated at the same time, so that at least one light is still visible during standstill;
- An uninterruptible power supply is mandatory;
- A synchronization of the wind farm is mandatory.

5.4.5 Norway

In Norway, structures between 60 and 100 metres shall have a rotor marked with a red, low-intensity light. Wind turbines between 100 and 150 metres tall should be marked with a low-intensity light on top and one low-intensity light on a lower level, with a distance between the lights not being more than 75 metres. Structures higher than 150 Meters, should be marked with a high-intensity light on top and low intensity-lights on lower levels.

5.4.6 Sweden

As far as possible the rules should meet ICAO standards: the light placed on the highest point. It is however proposed that windmills could have the lights on top of the nacelle. Windmills below 150m should be equipped with red, flashing light of medium intensity > 2000 Cd. Windmills higher than 150 metres should have white flashing light of high intensity > 100.000 Cd. These rules are in force until lights with good technical reliability can be installed in the tips of the turbine wings. High intensity light should be visible 1,5 degrees below the horizon and 3 degrees over the horizon. The light of medium intensity should be seen from the horizon and upwards.

The use of flashing lamps is not addressed in this study, as per the assumptions listed in Chapter 5 of this report.

5.4.7 United Kingdom

The UK's regulations and national policy are contained in a document entitled CAP764 "Civil Aviation Authority (CAA) Policy and Guidelines on Wind Turbines". In the UK, there is no requirement to light offshore wind turbines that are less than 150 metres tall. This means that the large wind farm "London Array" to the east of the Thames estuary is not lit to aviation. The 175 wind turbines are 147 metres tall. The wind turbines are however included in the electronic obstacle database that the UK Air Traffic Service provider, NATS, promulgates in the national Aeronautical Information Publication (AIP); see ENR 5.4 for details. Wind turbines and wind farm zones are included on other en-route navigation data, including en-route restrictions (ENR 6.5.1.1), the helicopter routes for the south North Sea (ENR 6.1.15.3) and the UK's 1:500.000 scale VFR chart (see example below).

Figure 6: UK VFR chart with 'wind farm' marked (Source – UK CAA)

Where wind turbines are lit, the UK permits the light to flash the Morse Code Letter 'W' to ensure that the aviation warning lighting is distinguishable from maritime lighting. This is only an issue where it is evident that the standard aviation warning lighting may generate issues for the maritime community. A number of existing wind farms (e.g. Barrow, Lynn & Inner Dowsing and Ormonde) are lit with steady lamps at the corners / periphery of the wind farm.

A reduction in lighting intensity at and below the horizontal is included in the requirements. In addition, reduction in lighting intensity is permitted when the visibility in all directions from every wind turbine is more than 5 km.

In relationship to wind turbines, the requirement to fit aviation obstruction lighting 'as close as possible to the top of the obstacle' is typically translated to mean the fitting of lights on the top of the supporting structure (the nacelle) rather than the blade tips.

Where wind turbines are located in areas close to low-level military flying areas (Tactical Training Areas and Low Flying Areas), a military requirement for Infra-Red (IR) lighting is noted.

5.4.8 USA

The U.S. Department of Transportation, Federal Aviation Administration (FAA) published their policy on obstruction marking and lighting in the advisory circular AC70/7460-1L, effective on 8 October 2016. Wind turbine farms are defined as a wind turbine development that contains more than three turbines of heights over 200 feet (61 metres) above ground level. Marking standards are:

- Bright white or light off-white paint on wind turbines has been shown to be most effective. If used, no lights are required during daytime;
- When a darker paint is used, the marking should be supplemented with daytime lighting.

The general lighting standards are:

- Flashing red (L-864) or white (L-865) may be used to light wind turbines
- Night time wind turbine obstruction lighting should consist of the L-864 aviation red-coloured flashing lamps;
- Any array of flashing or pulsed obstruction lighting should be synchronized or flash simultaneously;
- Light fixtures should be placed as high as possible on the nacelle, to be visible from 360 degrees.

In the same way as the Canadian regulations, the FAA Advisory Circular (AC) includes guidance material on the use of detection systems to allow the lights to be switched off when no aircraft are near the turbines. In addition, there are standards that relate to the configuration of the wind farm:

- Linear configuration: a light should be placed on each turbine positioned at each end of the line or string of turbines. Lights should be no more than ½ statue mile or 2640 feet from the last lit turbine. In the event if the last segment is short, push the lit turbines back towards the starting point to present a well-balanced string of lights.
- Cluster configuration: a starting point among the outer perimeter of the cluster, this turbine should be lit. A light should be places on the next turbine so that no more than a ½ statue mile gap exists. One-half statute mile is less than 900 metres; 804 metres.
- Grid configuration: select each of the defined corners of the layout to be lit, utilize the same concept of the cluster configuration. The gap between the lights here is up to 1 statute mile or 1,600 metres. Figure 26 in Appendix A to the FAA AC illustrates the required design.

6 Visibility of wind turbines

6.1 Introduction

In general, observers on the shore wish to reduce the amount of light that they can perceive emanating from wind turbines. The prime issues of perception are centred on the brightness of the lamp and whether or not the lamp flashes. Flashing can be produced by two sources; the lamp being turned on and off and the effect of the lamp as it reflects off the revolving turbine blades.

Using the material referred to in the documents mentioned in chapter 5, the following section explores the perception of light in different conditions (6.1), the perception of light onshore (6.3), the visibility of objects (6.4), strategies applied to minimise light onshore (6.5) and the final section (6.5) summarises the visibility of wind turbines.

6.2 The perception of lights by the human eye

Human eyes sense light slightly differently in darkness than in daylight. In daylight eyes are most sensitive to green light; are less sensitive to yellow and blue light; are only half as sensitive to orange and lavender light and are only one tenth as sensitive to red and violet light. Therefore, at a distance, a 100-watt green light bulb can be seen about 3 times farther than a red or violet bulb of the same light power, during the day. In darkness, the maximum sensitivity of human eyes shifts toward yellow-green wavelengths with the other colours staying at about the same sensitivity as above making, at night, red a light that humans poorly perceive[10].

Despite these differences in perception of the human eye to different colours, international regulations only permit two colours to be used; red and white. A re-evaluation of this regulation is outside the scope of the study.

A maximum distance that light, red or otherwise at day or night, can be seen is difficult to establish. Air quality, for one, affects the way that light is diffused and refracted. These effects mean that light from lamps that cannot be seen directly because they are low on the horizon are visible due to diffusion and light scattering. However, to make a determination of horizon distance, a calculation can be made using a simple spherical model of the earth; assuming no distortion, the effective horizon from a red lamp installed at a height of 150 metres on a wind turbine would be about 43 kilometres[11]. From this approach, some of the wind turbines at all three sites will, theoretically, be visible[12].

Work on the minimum distance that an object (unlit in the day and lit at night) can be readily seen is less well researched. An American study[13] into the visibility of onshore wind farm zones does provide

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[10] Adrian Poppa, Hughes Research Laboratories

[11] Earth radius (6378137 metres) plus 150 metres forms the hypotenuse of a right-angled triangle that has a base equal to earth radius. By Pythagoras, the third side (the horizon distance) is 43.7 kilometres.

[12] Wind farm zone Luchterduinen, populated with wind turbines that are 137 metres high, located 22.2 km from the shore, is regularly visible during the night according to RVO.nl.

[13] Wind Turbine Visibility and Visual Impact Threshold Distances in Western Landscapes, Sullivan et al, 2012

background material. The combination of minimum visibility and aircraft moving at speed is however poorly researched. This matter is further discussed in Chapter 9 of this report.

6.3 Perception of light onshore

In a widely quoted study, Wratten *el al* (2005) determined three distance thresholds for the perception of light from offshore structures and lighting:

- <13 km possible major visual effects;
- 13-24 km possible moderate visual effects, and
- >24 km possible minor visual effects.

The lamps in this study were coloured red. The report also noted, specifically for the lamps on a wind turbine's nacelle, that "lighting on turbines for navigational purposes may be visible at night and contrast with the background, but at the distance of most [wind farm zones located between 8 km and 25 km offshore] even the brighter (…) lights are likely to be seen as just a twinkle".

Wratten *et al* also found that the visibility of a wind turbine could be decreased by painting the wind turbine tower and blades in light tones such as off-white or light grey. However, the report noted that that the recommended colour of the wind turbines should be "judged for each offshore wind farm site based on its own geographic location, coastal orientation, elevation and prevailing weather and light conditions".

Research on visual assessment by Bishop and Miller (2005) found that distance and contrast are very good predictors of perceived impact. Their study, based on North Hoyle wind farm at 7 km off the coast of Wales, showed that in all atmospheres and lighting conditions (except a stormy sky), visual impacts decreased with distance. However, visual impact increased with increasing contrast.

In the Netherlands, onshore and offshore wind farm zones have generated complaints. Flashing obstacle lamps appear to generate more negative comment than steady ones. A study conducted on behalf of the national government, Province Flevoland, Zeewolde council and Nuon in 2015 for the light nuisance caused by the wind farm Prinses Alexia near Zeewolde[14] concluded that residents preferred steady obstacle lamps rather than flashing ones. The study showed that the flashing lamps were judged to be unacceptable by 76% of the respondents against 26% for the steady lighting. The study also investigated attitudes to varying the intensity of the obstacle lighting. Dimming the obstacle lighting during periods with good visibility was felt by respondents to be a better option than not having the obstacle lamps flash. The investigation did not enquire about the combination of both measures. It is assumed that variable intensity steady obstacle lighting would be most preferred option

6.4 Visibility range

Regardless of the uncertainties regarding the maximum distance at which an observer can perceive objects in the distance, from practical experience at wind farm zones Alexia and Luchterduinen, there are moments at which an object at 20 km from the coast will be visible on a clear day. The Dutch

[14] It should be noted that the Prinses Alexia wind farm is not an offshore installation but is located on land.

meteorological institute, KNMI, has a network of over 20 stations in the Netherlands that collect, among other data, visibility data. This study makes use of work that was previously prepared for the wind farm sites in the North Sea. Specifically, several Environmental Impact Assessments (*Milieueffectrapport* or MER) were used to obtain data from the coastal stations at Vlissingen, Hoek van Holland, IJmuiden and De Kooy (Den Helder) is reported. The KNMI's data, as used in these studies, is summarised in Appendix F Visibility Range.

For all three locations, the daytime visibility exceeds 20 km for between 20 and 30 percent of the time. The study concluded that the visibility of wind turbines is "[…] strongly dependent on the brightness of the weather and the distance between observer and object. Many people will see that something is' but often not see clearly "what" it is".

As a final point, it should be noted that the documents reviewed did not explicitly refer to the visibility of lamps on wind turbines at night.

6.5 Strategies to minimise light onshore

As described above, the *Informatieblad* published by the ILT have focused on the following methods:

- The use of steady lamps instead of flashing ones;
- Minimising the number of lamps installed using contour lighting, and
- Dimming the lamps during periods of good visibility.

Other methods that have been discussed in studies elsewhere in the world that could be considered include:

- Masking the lamps to ensure that the effective horizon of the light is less;
- Painting the towers and turbine blades in a colour other than white;
- Switching the lamps off during those periods when there are no aircraft in the vicinity, and
- Switching the lamps off permanently and utilising infra-red lighting.

The preference for a steady lamp over a flashing one is described above. The use of a steady lamp is prescribed by the Site Decisions for two wind farm sites and is included in the ILT *Informatieblad*. Future Wind Farm Site Decisions for Hollandse Kust (zuid) and (noord) will prescribe steady and dimmable lamps.

6.6 Summary – visibility of wind turbines

The height of the wind turbines combined with the prevailing visibility makes the light from any lamps installed on the wind turbines regularly visible from the shore. Experience elsewhere shows that the most frequently used mitigation to the reduction of nuisance from this light is the use of steady lamps and not flashing ones. This measure, according to community groups, is considered to be effective. A reduction in visibility will also be possible by considering the additional measures described in this paragraph.

7 Inventory of assessed solutions

7.1 Introduction

This chapter describes the following possible solutions:

- Fewer lamps;
- Lower light intensity;
- Painting the tower and turbine blades off-white or grey / camouflaging;
- Shielding the lamps;
- Detection systems, and
- Infra-red systems.

It should be noted that the public's experience of lighting leads to a preference for a steady lamp over a flashing one, as described above.

7.2 Fewer lamps

Prior to considering whether or not fewer lamps can be installed, it is necessary to determine how many wind turbines will be constructed. Reviewing the number of wind turbines that are planned to be located in the Borssele Wind Farm Site (BWFS), the requirements are as follows:

Location	Minimum & maximum energy to be produced	Assumed production per turbine	Surface area	Planned number of turbines for the location
BWFS I	351 - 380 MW	8 MW	68 km²	43 - 47
BWFS II	351 - 380 MW		69 km²	43 - 47
BWFS III	330 - 360 MW		70.7 km²	41 - 45
BWFS IV	351 - 380 MW		75.1 km²	43 - 47
BWFS V	20 MW		0.6 km²	2

Table 4: Planned number of wind turbines

Based on the planned number of wind turbines, the following configurations are explored to reduce the number of lights:

1. Flashing contour lighting (with max 900 metres distance between lights) following ILT *Informatieblad;*
2. Continuous lighting with grid configuration, following FAA Advisory Circular;
3. Combination of 1 & 2: continuous burning contour lighting (in four variations).

For the purpose of this assessment, several indicative layouts of Borssele wind farm were constructed with the aim to assess the feasibility of the proposed solutions. It should be noted that the layout is a model that places the turbines in a geometric layout. There is no suggestion that these layouts represent an energy efficient distribution of turbines. Whilst the diagrams in the *Informatieblad*, FAA AC and other sources all show a regular geometric pattern, it should be noted that, in reality, the wind turbines will not be constructed in a perfectly regular shape having consistent distances between them. In addition to being laid out with the greatest possible distance between wind turbines and aligned with the prevailing wind, variations in ground, soil and water conditions will result in the configuration of the wind farm not being wholly regular.

None of the designs below take the text of paragraph 3.2 into consideration; all wind turbines within a range of 5 NM of a helideck will be illuminated when night operations take place.

7.2.1 Contour lighting

As permitted by ICAO Annex 14, a number of national requirements, including those contained in the *Informatieblad*, include the possibility of installing fewer lamps on the wind turbines; i.e. not having every turbine lit by steady lamps.

The concept is known as contour lighting. In this model, lamps are installed on turbines at a distance not exceeding 900 metres. In addition, the turbines that form the corners of the wind farm are also lit. The *Informatieblad* includes, in Appendix 3, an illustration of contour lighting. It is reproduced below. This model of contour lighting, the *Informatieblad* requires that the lamps will be flashing. Steady red lamps are only permitted under the terms of the *Informatieblad* when all the turbines are lit.

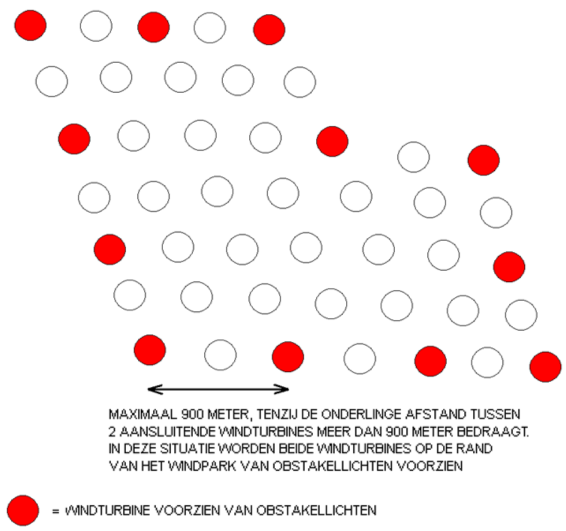


Figure 7: Configuration contour lighting according to ILT *Informatieblad*

It is noted that the Site Decision prescribes steady lamps. The use of a steady lamp is permitted in the ILT *Informatieblad*; (see 5.1.a of the *Informatieblad).* However, the document does not link steady lamps to contour lighting unless a safety case can be successfully made. This is discussed elsewhere in this report.

The figure of 900 metres is also used in the regulations and guidelines published by the United Kingdom, Denmark, Canada & Australia. Two countries have taken different approaches; Finland and the United States. The Finnish model (see illustration below) mandates different coloured lamps rather than a reduction.

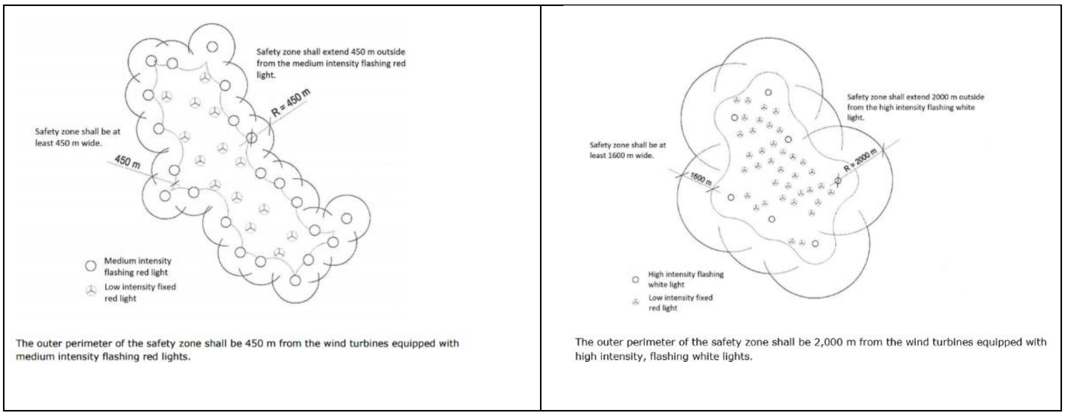


Figure 8: Model of contour lighting from Finnish Transport Safety Agency

The wind turbines are required to be located at least 820 metres apart from each other, according to the construction requirements. If the turbines are equally spaced at a distance of 820 metres, 75 to 90 turbines would be located in each of the three sites, BWFS I, II and IV. This is a greater number than permitted when considering an 8 MW turbine. As a result, it is concluded that the 900 metres contour lighting, considering the configuration of the parcels of the wind farm zones, is not viable.

It should be noted that the figure of 900 metres distance between lights has not been chosen arbitrarily. Research quoted by the ICAO Visual Aid Working Group (VAWG) has shown that, at a distance of 1.9 kilometres, a typical general aviation aeroplane at low level has a 900-metre-wide field of vision out of the cockpit. This conclusion is derived from the calculation made for the mast with supporting wires described in A-13 of FAA Advisory Circular 70/7460-1L. This is based on the sight limitations that apply to a general aviation aeroplane flown by a single pilot at a speed of 165 knots

A 1991 study[15] by the Australian Transportation Safety Board (ATSB) demonstrated the field of sight limitations that apply to the typical general aviation aeroplane as flown by a single pilot. A graphic representation of that work is shown in Appendix G.

However, the use of two crew aircraft in operations above and in the wind farm zones, increases the field of sight that crews have. Examples of two-crew aeroplanes are the Dornier 228 from the Coastguard and the broad cockpits of helicopters. Such an approach, should it be acceptable to the ILT, requires the exclusion of single-pilot traffic from the areas around the wind farm zones. This is discussed elsewhere in the report.

[15] Limitations of the See-and-avoid Principle, ATSB, April 1991

7.2.2 Grid configuration, based on FAA regulation

The United States, in Advisory Circular (AC) 70/7460-1L (dated 8 October 2016), offers three models of contour lighting for wind farm zones. Paragraph 13.3 of the AC states:

1. Linear—wind turbine farms in a direct, consecutive configuration, often located along a ridge line, the face of a mountain, or along borders of a mesa or field. The line may be ragged in shape or be periodically broken, and may vary in size from just a few turbines to many turbines forming a line that is several miles long. 2. Cluster—wind turbine farms arranged in circular configuration. A cluster is typically characterized by having a pronounced perimeter, with various turbines placed inside the circle at various, erratic distances throughout the center (sic) of the circle. 3. Grid—wind turbine farms arranged in a geographical shape, such as a square or a rectangle, in which the turbines are placed a consistent distance from each other in rows, giving the appearance that they are part of a square pattern.

The likely wind farm layout in the areas under investigation are such that the grid system is considered to be the most applicable. The AC (paragraph 13.5.2) permits the following lighting pattern: *Wind turbines within a grid or cluster should not have an unlighted separation or gap of more than 1 sm (1.6 km) across the interior of a grid or cluster of turbines.* The following image, illustrating this, is taken from Appendix A to the AC. The following paragraph explores the feasibility to apply a grid configuration with 1600 and 1200 Meter distance.

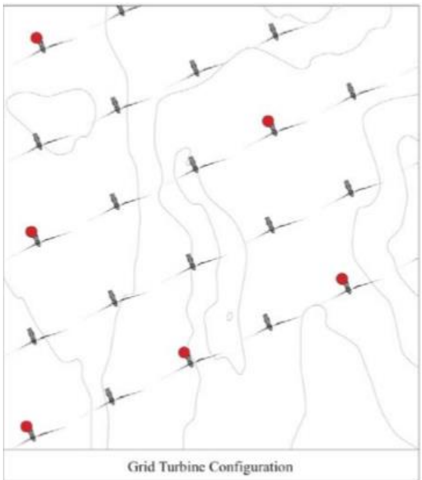


Figure 9: Configuration grid lighting according to FAA Advisory Circular (AC) 70/7460-1L

A geometric layout at 1,600 metres - equal to the distance that the FAA in the USA allows - was attempted. In this layout, too few turbines could be located. For example, BWFS I would only have 34 turbines equally spaced within the site. The use of FAA's grid spacing (a lamp every 1,600 metres) would result in all of the turbines having lamps as it is not possible to apply any reduction when using a separation of 1,200 metres.

The following figure shows a possible configuration for the BWFS on a 1,200 metre grid. The layout in the figure is for an equidistant layout of 1,200 metres between turbines (with the exception of the two in BWFS V, which are spaced at 820 metres).

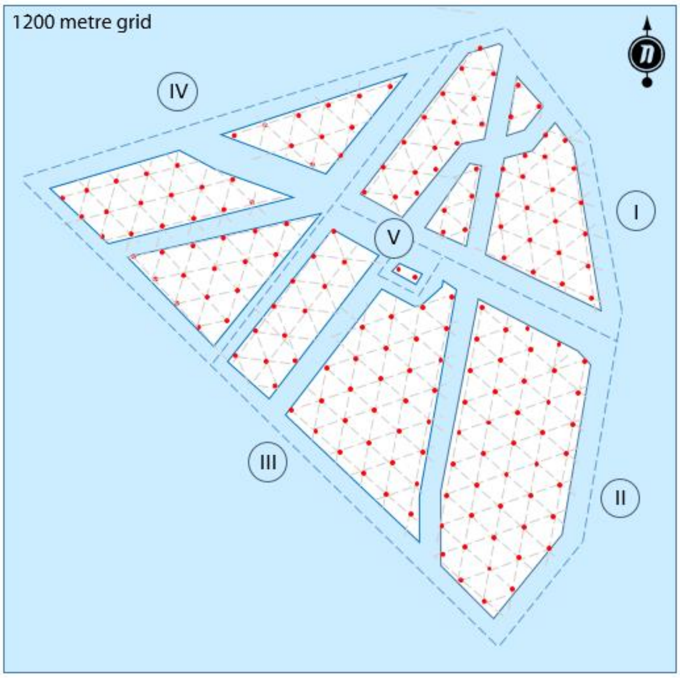


Figure 10: Indicative layout Borssele on a 1,200 Meter grid

The application of a 1,200 Meter grid would result in a total 179 wind turbines, all equipped with a lamp (see the table below). It is important to note that each lamp is actually a pair of co-located lamps, one on the mast and one on the nacelle.

Location	Turbines planned, with lamps
Borssele I	45
Borssele II	43
Borssele III	45
Borssele IV	44
Borssele V	2
Totals	179

Table 5: Number of wind turbines / lamps with a 1,200 metre grid layout

7.2.3 Continuous burning contour lighting (alternative proposals)

This section explores a new and not yet accepted proposal to reduce the number of lamps in wind farm zones by applying continuous illuminated contour lighting (as applied in the UK) to a grid configuration (following FAA Advisory Circular). Consequently, all following configurations, with >900 metre distance between lights, need to be assessed by the Dutch authorities before application. Before discussing alternative proposals, it should be noted that the application of synchronised flashing lamps around the periphery of a wind farm (as per the ILT *Informatieblad)* is permitted and, as such, does not form an integral part of this analysis. Also, Site Decistions of Hollandse Kust (zuid) I and II prescribe steady and dimmable lamps.

The following configurations are proposed, all based on a 1,200 Meter grid configuration:

- Variation 1: Contour lighting of all parcels;
- Variation 2: Contour lighting of the entire wind farm;
- Variation 3: Contour lighting of parcels north and south of channel;
- Variation 4: Contour lighting of parcel I & II, and parcels II, IV & V.

For these alternative proposals, it is argued that a maximum of 900 metre between lamps should be in line of sight. That means that, when a pilot approaches the wind farm, nearby or further away, a maximum distance between lamps shall be 900 metre. The figures illustrating each of the four variations in the following paragraphs, indicate also the circumstances this condition cannot be guaranteed. These areas are marked in red on the maps. However, as explained above, it is not expected that the final design of the wind parks will match a geometrical grid due to wind and geology. This automatically results into a less regular design, which limits the instances the line of sight between lamps is greater than 900 metres. Lines of sight that exceed 900 metres are shown in the figures below with a light orange stripe.

Safety issues related to the application of contour lighting include:

- What is the greatest distance between lamps that is acceptable?
- Can a case be made for the use of steady lamps and not flashing lamps?

An analysis of the following is made in chapter 8.3.1 below:

- Increasing the boundary lighting distance to a value above the ICAO value of 900 metres but below the distance allowable in the US model (1,600 metres), and
- Using only steady lamps with contour lighting.

It should be noted that the issue of contour lighting requires evaluation against three specific situations:

- Lighting patterns for flight greater than 5 NM (9,3 km) from the edge of a wind farm or flight 1,000 feet above the wind farm;
- Lighting patterns for flights that are less than 5 NM from the edge of a wind farm or fly low (less than 1,000 feet) over the wind farm, and
- Lighting patterns for flight within the wind farm.

7.2.3.1 Variation 1: Contour lighting of all parcels

If the ICAO / *Informatieblad* limit for boundary lighting is raised from 900 metres to 1,200 metres, the boundaries of the four Borssele wind farm sites, I to IV, could be lit, leaving the inner turbines without lamps. Having four separate boundaries would permit the following reduction in lamps.

Location	Turbines planned	Turbines inside boundary (marked in black in the figure below)	Turbines forming the boundaries (marked in red in the figure below)
Borssele I	45	12	34
Borssele II	43	23	21
Borssele III	45	15	28
Borssele IV	44	9	35
Borssele V	2	0	2
Totals	**179**	**59**	**120**

Table 6: Number of wind turbines / lamps – variation 1

The above schedule of lighting would allow a reduction in lamps of 33 %. An indicative outline is presented in the figure below.

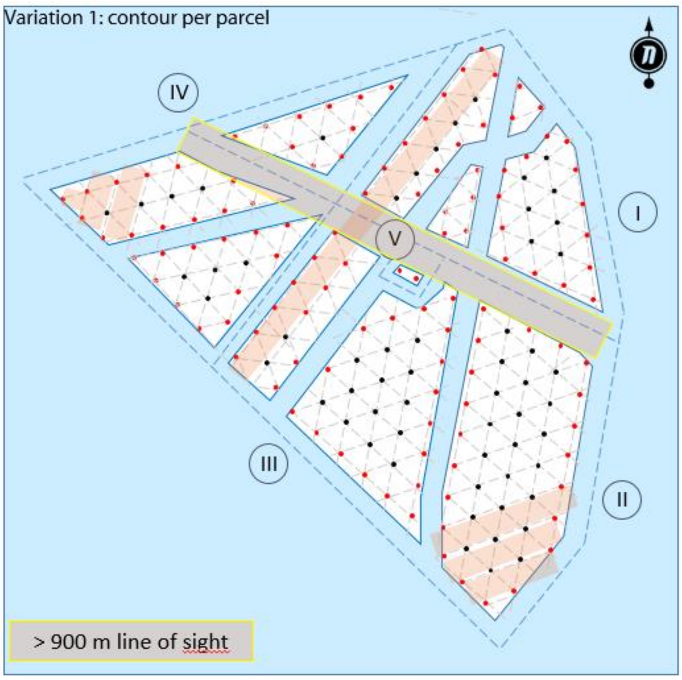


Figure 11: Variation 1: Indicative layout of 1,200 Meter grid with contour lighting per parcel

7.2.3.2 Variation 2: Contour lighting of the entire wind farm zone

Variation 2 explores the option to apply contour lighting around the entire wind farm zone. This would allow a reduction of 73%, based on the indicative layout in the figure below.

Location	Turbines planned	Turbines inside boundary	Turbines forming the boundary
Borssele	179	131	48

Table 7: Number of wind turbines / lamps – variation 2

It should be noted however that the further one windmill is located behind the other, the less visible the light will be due to this distance. Therefore, the instances at which the condition of a maximum of 900 metre of lamps within line of sight cannot be guaranteed, might increase.

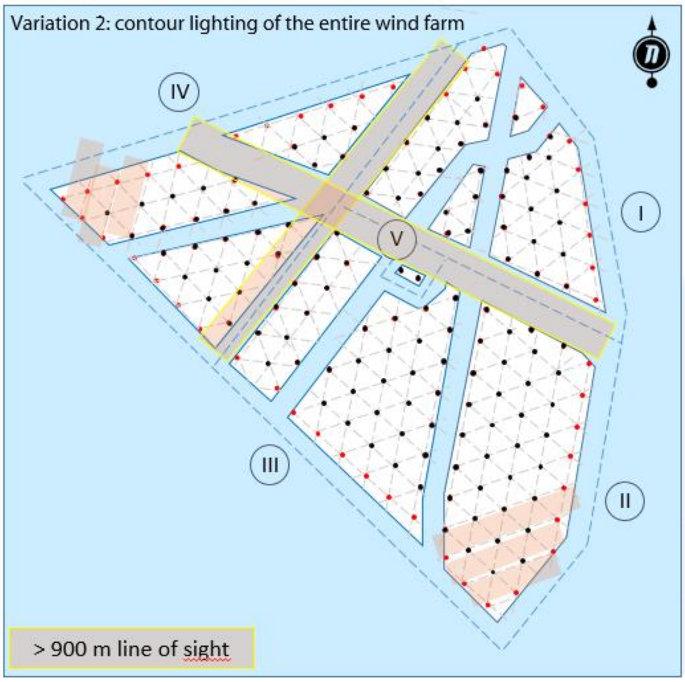


Figure 12: Variation 2: Indicative layout of 1,200 Meter grid with contour lighting for entire wind farm

7.2.3.3 Variation 3: Contour lighting of parcels north and south of channel

Variation 3 explores the option to apply contour lighting to the parcels north and south of the channel. This would reduce the number of lamps by 63%. The figure below shows that there are quite a few areas at which the condition of maximum of 900 metre of line of sight between lamps, cannot be guaranteed.

Location	Turbines planned	Turbines inside boundary	Turbines forming the boundary
North	57	30	27
South	122	82	40
Totals	**179**	**112**	**67**

Table 8: Number of wind turbines / lamps – variation 3

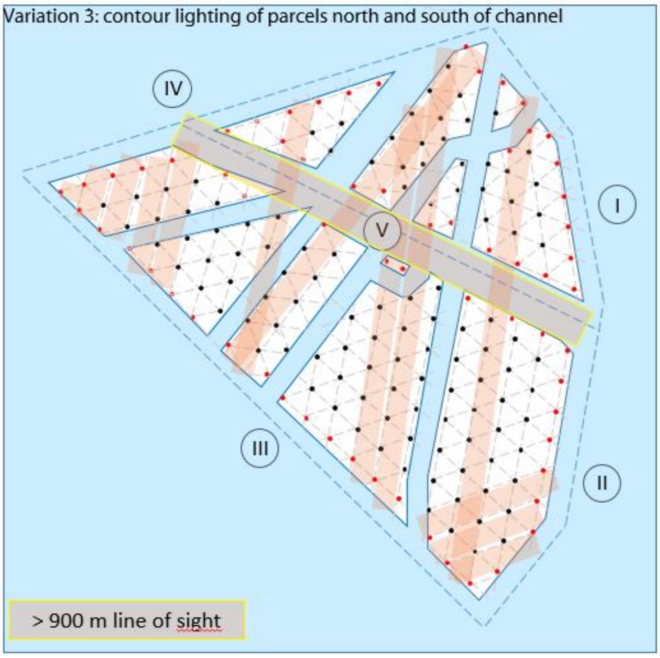


Figure 13: Variation 3: Indicative layout of 1,200 Meter grid with contour lighting of parcels north and south of channel

7.2.3.4 Variation 4: Contour lighting of sites I & II, and sites III, IV & V

Variation 4 explores the contour lighting of sites I & II combined, and sites III, IV & V together. This would reduce the number of lamps by 59%, as indicated in the table below.

Location	Turbines planned	Turbines inside boundary	Turbines forming the boundary
Borssele I & II	90	53	37
Borssele III, IV & V	89	52	37
Totals	**179**	**105**	**74**

Table 9: Number of wind turbines / lamps – variation 4

The figure below indicates the configuration of wind turbines and lamps.

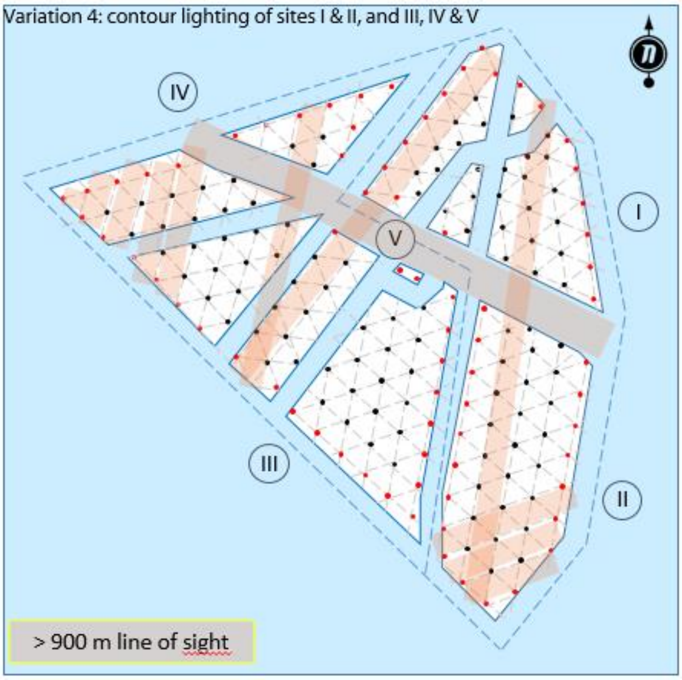


Figure 14: Variation 4: Indicative layout of 1,200 Meter grid with contour lighting of sites I & II and III, IV & V.

7.2.3.5 Summary of the four variations for fewer lamps

In summary, the different variations assessed all appear to be possible. However, variation 1 and 2 seem to give the fewest number of sight lines that do not meet the modified 900 metre distance between lamps that To70 proposes (but this doesn't consider yet the maximum distance the lamps can be located behind each other to guarantee the 900-metre line of sight). For each of these variations the non-geometric final design (see appendix B for an example) may be of benefit in reducing the number of the sight lines that do not meet the above. In addition, the developer of the wind farm site may illuminate one of more wind turbines in the centre of the parcel to meet the requirements. It is not proposed to remove the lamps from midway up the mast in any of the above variations. Doing so would adversely affect the form created by the lighting, leading to possible undesirable visual illusions.

7.3 Lower light intensity

Many States permit that the intensity of the lamps installed to be reduced during the twilight periods and at night when good visibility conditions prevail. This is not an issue included in ICAO Annex 14. The *Informatieblad* permits a reduction to 30% intensity when the visibility is between 5,000 metres and 10,000 metres. A further reduction to 10% intensity is permitted when the visibility is greater than 10,000 metres. This applies during the twilight periods and at night. Any required daylight lighting shall be set to 100 percent intensity. The United Kingdom permits a reduction to 10% when the visibility is 5,000 metres or greater during the twilight periods and at night. The safety issues related to the use of shielding is, primarily, are the reduction illumination values adequate? An analysis is therefore made in chapter 8.3.2 below of:

- The UK's policy that permits a reduction to 10% when the visibility is 5,000 metres or greater during the twilight periods and at night, and
- A reduction in the amount of light that is produced during the day, permitting a reduction to 30% when the visibility is 5,000 metres or greater.

It should be noted that the lower light intensity requires evaluation against two specific situations:

- Light intensity for flight greater than 5 NM (9,3 km) from the edge of a wind farm or flight 1,000 feet above the wind farm, and
- Light intensity for flights that are less than 5 NM from the edge of a wind farm or low flight (less than 1,000 ft) over the wind farm.

An additional measure to reducing the intensity of the light cast by a lamp, is the reduction in its reflection off the structure of the wind turbine structure and its blades. The *Informatieblad*, as per ICAO, requires the wind turbine to be painted white. The ICAO VAWG has, in the past, noted that *"Painting the blades and support mast white in colour [...] as opposed to grey [...] gives the best possibility for conspicuity. [The VAWG members] do not have data for this paper to show the amount of time that grey merges with the background versus the merging of white. However, since grey has the appearance of white for direct sun conditions, and grey is intentionally used to reduce conspicuity, it is surmised that white paint is the overall better choice"*. However, the authorities in Denmark and the United States both allow the wind turbine to be painted with a light grey colour.

The *Infomatieblad* permits four tints of the colour white and one of grey to be used on the towers and turbine blades; RAL 9001 (Cream), RAL 9003 (Signal White), RAL 9010 (Pure White), RAL 9016 (Traffic White) and RAL 7035 (Light Grey). The contrast between these colours is shown in a diagram below. It should be noted that the exact colour, as it would look on a wind turbine, is not shown here.

RAL 9001	Crèmewit	Cream	Cremeweiß
RAL 9003	Signaalwit	Signal white	Signalweiß
RAL 9010	Zuiverwit	Pure white	Reinweiß
RAL 9016	Verkeerswit	Traffic white	Verkehrsweiß

Figure 15: Colours to be used to paint towers and turbine blades (Source: www.ralcolor.com)

The ILT guidance is the same as that in most other States. The last option, RAL 7035, may only be applied in combination with flashing white lamps. Such a combination is not seen as a realistic option for reducing the visibility of the wind farm zones from the shore. The USA permits light grey without the need for additional lamps. No material could be found by To70 to quantify the reduction in visibility of grey versus white painted structures. Nor was it possible to identify any information on reduction in the amount of reflection resulting from the use of grey paint. This is a possible area of research for the future. A related topic is the camouflaging of the wind turbine. This is discussed below in 8.1.4.

7.4 Shielding the lamp

One of the issues that Annex 14 and the *Informatieblad* discuss is the need to ensure that the obstacle lighting is conspicuous for maritime uses, but that the same is not confusing to maritime users. To achieve the first objective, the lamp should be visible below the horizon. It is the configuration and number of lamps that are fundamental to ensuring that maritime users are not confused; paragraph 5.5 of the *Informatieblad* states that "*De verspreiding van het licht onder het horizontale vlak mag worden beperkt om verwarring voor de scheepvaart te voorkomen is [….]*"

The *Informatieblad* continues with a warning in footnote 2 that an acceptable level of shielding is not likely to have any significant effect on reducing the visibility of the lamp from a large distance. The definition of a distance from which the wind farm edge must be visible to maritime users was sought for input into the safety assessment. The IALA Recommendation on the Marking of Man-Made Offshore Structures (Number O-139), dated December 2008 was used as a source. The source document has no specific recommendation for this topic about the marking of wind turbines. However, the lamps that are required to light wave and tidal energy extraction fields that should have a nominal range of at least 5 NM[16]. Safety issues related to the use of shielding include:

- Are the lamps adequately visible to aircraft?
- Are the lamps adequately visible to maritime users?

The analysis required would address the issue of shielding lamps in such a way that they are visible at all angles above the horizon but are only visible below the horizon at a range of between 5 NM (9.3 km) and 10 NM (18.5 km). With no information available on whether or not such a screening is possible, the technical feasibility of this option is not demonstrated and thus. The risk calculation below is not wholly performed. Shielding the lamps is not considered, in this report, as a realistic option.

7.5 Detection systems

During the literature study a number of technological solutions were noted as being available to reduce the time that obstacle lamps are lit. The principle here is that the obstacle lamps are left switched off until they are activated by one means or another so as to serve their design purpose – a warning to aircraft in the vicinity. If there are no aircraft in the vicinity, the lamps remain switched off. Three primary means to activate the lights have been identified:

- transponder detection;
- radar detection, and

[16] See paragraph 2.4.2.3 of IALA document

- pilot controlled (VHF-activation) switches.

The benefit of such a solution is that it will reduce the amount of time that the lamps are switched on. For example, there are no oil and gas activities near the BWFS. Thus, there are few aircraft movements in the vicinity of the wind farm. The use of a detection system would mean that the lamps were switched off for the majority of the time. Based on the current location of oil and gas platform that have helidecks, this is less so for the Hollands Kust (zuid) wind farm and even less so for the Hollands Kust (noord) wind farm. Nevertheless, a detection system would have an impact on the amount of time that the lamps were switched on. The effect, from the perspective of the observer on shore, of the lamps repeatedly being cycling from off to and back to off again has not been investigated.

Whilst pilot controlled (VHF-activation) switches are commonplace for the activation of runway lighting systems in parts of the world, the related human factors to their use in this application has led to them being excluded from the study. Two other activation methods are considered; transponder and radar detection. These are similar in function to each other, but their source of detection is different. A review of material available within the within the wind turbine industry shows that the radar detection system appears to be more common than the transponder one.

Safety issues related to the use of a detection system include:

- Fail-safe mechanism – do the lamps switch on when the detection system fails?
- Do the lamps only switch on when low level traffic is in the vicinity?
- Is the detection system set up to ensure that low level traffic in the vicinity is detected all around the wind farm?
- Is such a system acceptable to maritime users?

An analysis is made below of:

- The potential safety impact of the installation and use of a detection system.

7.6 Infra-red marking

Several aviation users make use of night vision googles (NVG) during flight operations. Markings that show up well under infra-red can be easily seen by such users. Such markings are not visible to the naked eye. An inventory of the users of night vision googles amongst the aviation users shows:

- Oil and gas operators – some of the larger operators are NVG-capable, most small ones are not;
- Most military aircraft are NVG-capable;
- Coastguard flights – the current, civilian, helicopter provider is not NVG-capable nor is the Dornier 228 currently used for fixed-wing operations;
- Police helicopters – NVG-capable;
- Air ambulance helicopters – NVG-capable
- General aviation –general aviation aircraft are not NVG-capable.

In summary, the fleet of aircraft likely to operate in North Sea airspace at low level is not wholly NVG-capable. Ensuring that all oil and gas operators and all coastguard aircraft are NVG-capable is pre-requisite to the use of infra-red markings on the wind turbines.

The application of both passive and active infra-red markings by military and law enforcement agencies is common. As an example of active marking, some emergency vehicles make use of flashing LED lamps[17] that are only visible in the infra-red range are used to allow helicopters equipped with night vision devices to better follow the vehicles at night. The distance at which this system can be seen is not known.

Anecdotal evidence suggests that a typical resolution under infra-red imaging is that a human can be seen from about 300 metres. With additional information, the use of infra-red markings could be considered as a suitable means of providing a warning to aviation users. However, as night vision googles are not used by all aviation users and their acquisition and implementation is costly – aircraft cockpits require modification - the introduction of infra-red markings can only be an additional means of marking the obstacles.

Due to the issues mentioned above, To70 believes this technology cannot be applied as a stand-alone lighting system. As a consequence, the application of infra-red markings won't reduce the visibility of the wind farm sites. Therefore, infra-red markings are excluded from the risk assessment in this document.

[17] Hella RTK7 – KL-LM5 infra-red lighting module is an example of such a system

8 Compliance & risk assessment

Using all the information gathered in the initial stages of the project (see chapters 3 to 6 above), an assessment of the possible solutions (see the inventory in chapter 7 above) will be made regarding in how far the solutions are complaint with the current legislation and what risks are associated with the possible solutions.

The risk assessment, described below, consists of a qualitative analysis in which the risk of the various solutions are assessed. A 5 x 5 risk matrix is used for the risk analysis. This is a standard method used in aviation (see 2.14 of the ICAO Safety Management Manual (ICAO Doc. 9859)). This method is used to estimate the frequency with which an event can take place and the impact that an incident if it occurs. The goal of this analysis is to find a solution with an acceptable level of safety.

Part of the analysis includes an evaluation of any mitigation measures. This allows higher risk scores can be reduced. By way of an example: if the obstacle lighting was to be switched off totally, this would be unacceptable. The introduction of a mitigation measure such as a detection system that turned the lights on when an aircraft was nearby could be used to lower the risk associated with a pilot not being alerted when close to an obstacle.

The risk-matrix assesses generic solutions and models, and aims to support the application for approval of specific designs and lighting plans. It is assumed that approval shall be forthcoming when these generic solutions are customised for each wind park.

8.1 Compliance with aviation requirements

Compliance in this instance refers to the ILT's *Informatieblad*. Where proposals below deviate from the document, individual risk elements are identified and analysed below. However, all of the elements identified in this study are compliant with the Wind Farm Site Decisions made for the offshore wind farm zones.

8.1.1 Distance between lamps, when using contour lighting, is greater than 900 metres

The non-compliance is only partial as it is possible to create a field of sight through the wind farm, as demonstrated below, that shows two lamps in a 900-metre field of sight for the vast majority of positions around the wind farm. The 900-metre requirement derives from a scenario involving general aviation aeroplanes approaching two solitary towers (and their guy ropes) in low visibility. The offshore wind farm has very different physical properties. In addition, the risk assessment will include the creation of Restricted Airspace above each wind farm, improved charting and the creation of obstacles for obstacle databases.

When considering contour lighting that is applied to all parcels within the Borssele wind farm, the figure below gives an indication of the instances when the gap between lamps visible from the edge of the wind farm will be greater than 900 Meters (figure 16, left). As shown, this is only the case in a few directions of flight. It should be noted however that the number of instances at which the two or more lamps are visible in a field of sight that is greater than 900 metre will be higher for the other assessed variations.

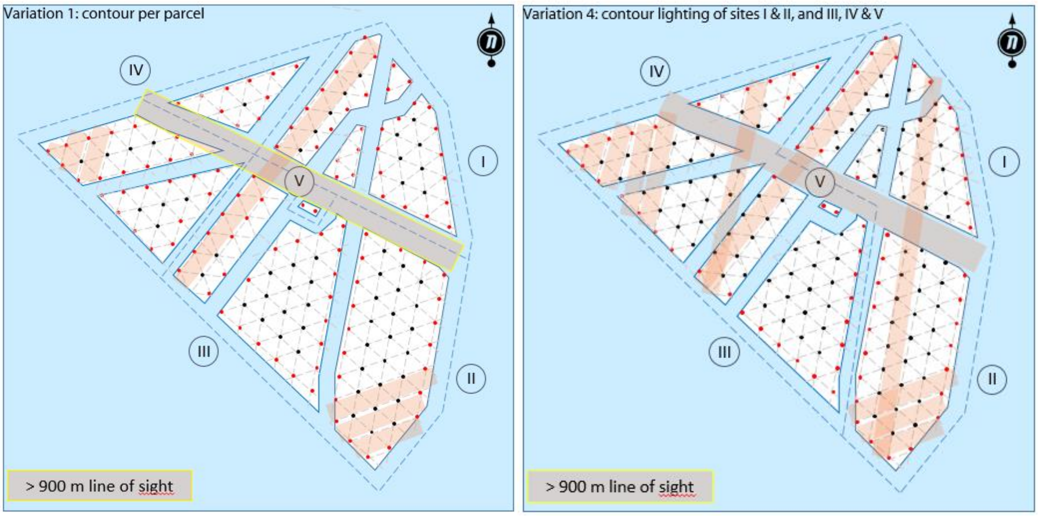


Figure 16: Instances with >900 Meter line of sight with 1200 Meter grid and contour lighting for two variations

The different variations assessed all appear to be possible, but variations 1 and 2 seem to give the fewest number of sight lines that do not meet the modified 900 metre distance between lamps that To70 proposes. This assessment does not take into account yet the visibility of lamps in the distance, although this is a requirement to guarantee a 900-Metre line of sight. for instance variance 2 (contour lighting of the entire wind farm zone) seems to give few instances at which the two or more lamps are visible in a field of sight that is greater than 900 meter, but in some cases the lamps are situated 15 to 20 km behind each other. Therefore, the option to apply contour lighting only to the outer border of the whole wind farm zone (without mitigating measures) is considered a less viable option.

Based on the currently available information, it is not yet possible to define the maximum distance between lamps to guarantee a 900-metre line of sight. At the moment of writing the report, information about the visibility of wind farm lamps was not provided by manufactures. The International Association of Lighthouse Authorities makes use of Allard's Law to calculate the nominal range of effective intensity of a lantern by means of Allard's Law for the development of light houses (see also section 8.1.3). However, it is not clear whether this theoretical model can be accurately applied to aviation purposes. Additional study, for instance by means of a simulation study, is recommended.

8.1.2 Lamp used for contour lighting is steady, not flashing

The ICAO Aerodrome Design Manual, Part 4, Visual Aids, is a supplement to ICAO Annex 14. The Aerodrome Design Manual discusses the use of both steady and flashing lamps in the marking of obstacles. Paragraph 14.2.4 of the Aerodrome Design Manual discusses the adequacy of steady red lamps at night and notes that the flashing lamps may be unacceptable to local communities. The following paragraph addresses a number of relevant research documents and practical applications of obstacle lighting. It is of note that no one solution, steady lamps or flashing lights, are universally applied.

Detailed study into the differences in perception between flashing and steady lamps has not been performed as the current energy regulations for the North Sea wind farm zones prescribe the use of steady lamps. The review of requirements in force in different countries (see paragraph 6.4) shows that opinions are evenly divided with some countries requiring steady lamps and others flashing ones.

Little documentation analysing the benefits of one system over the other was found. Whereas numerous studies discussed the optimum frequency for a flashing lamp, a US Coast Guard manual noted that "flashing a lamp, however, also decreases the perceived intensity of a lamp from its steady burning value" (Aids to Navigation Visual Signal Design Manual, COMDTINST M16510.2A. paragraph 2.B.2.c.).

In addition, the United Kingdom has permitted steady lamps to be placed at the corners of wind farms (e.g. Barrow, Lynn & Inner Dowsing and Ormonde). In the Netherlands, radio masts such as those close to Lelystad Airport also make use of steady red lamps. Lastly, the proposal in this document is intended to be applied to offshore wind farms only. The justification for this is the isolated location of offshore wind farms and the lack of background lighting. Steady lamps applied to wind farms on the land may be 'lost' in the clutter of town or road lighting.

In NLR's report (reference CR-2014-508, dated June 2015) into the lighting of the Prinses Alexia onshore wind farm site, the use of synchronous flashing lamps was recommended as being essential for contour lighting when intermediate wind turbines were then not lit as obstacles. In terms of the lay-out of the wind turbines in the wind farm, the NLR's position is supported. The Prinses Alexia wind farm consists of three non-parallel lines of twelve wind turbines each. The lay-out of this wind farm does not lend itself to contour lighting because its shape is difficult to perceive as a single homogenous form. In addition, offshore wind farms are in areas with little or no background lighting and are more easily perceived. Therefore, the NLR's recommendations are not applicable to the contour lighting of the offshore wind farms under consideration in this report.

8.1.3 Light intensity reduced at a lower visibility than defined in the *Informatieblad*

An alternative means of compliance was considered that would allow a reduction in light intensity that is less that defined in the *Informatieblad*. The proposal studied uses the same criteria that are currently applied in the United Kingdom; a reduction of 90% intensity with a visibility of 5 km or more.

The range at which a lamp can be detected is of importance from both the point of view of not being able to see a lamp from the shore and the lamp being clearly visible to flight crew members. For flight crew members, the closure rate to an obstacle should also be considered as this has a relationship to the reaction time to identify the obstacle and manoeuvre to avoid it as required. The international maritime standards body International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) publishes relevant material from the point of view of navigation lights for shipping. Three standards are particularly relevant to this study:

- IALA Recommendation E-200-2, Marine Signal Lights – Part 2 - Calculation, Definition and Notation of Luminous Range, Edition1, December 2008
- IALA Recommendation E-200-3 – Marine Signal Lights, Part 3 – Measurement, Edition 1, December 2008
- IALA Recommendation E-200-4, Marine Signal Lights - Part 4 - Determination and Calculation of Effective Intensity, Edition 1, December 2008

IALA document E-200-2 contains detailed information on calculating the nominal visual range of a lamp. The calculation is based on Allard's Law. This law relates four elements to each other:

- the illuminance produced on a surface (in this case, the viewer's eye) by a light source;
- the luminous intensity of the source;
- the distance *d* between the surface and the source, and
- the atmospheric transmissivity *T*, which is an assumed constant.

IALA has produced calculation tables for both day and night conditions. One element that is not included is the effect of background lighting on the illuminance of the light source being measured. As this part of the study is concerned with night time conditions, background lighting is relevant. The IALA recommendation has included the effect of background lighting into its guidance material (see IALA E-200-2, 3.1) by computing that 'minor' levels of background lighting will reduce the illuminance of a light source by a factor ten. 'Substantial' levels of background lighting have a factor 100 effect. Both terms here are subjective. Considering the fact that the wind farm sites are isolated at seas, it may be assumed that background lighting does not need to be considered.

The nominal range or effective intensity of a lantern comes from the following calculation known as Allard's Law documented in IALA Recommendations E-122 (2001) and E-200-2 (2008):

$$I_e = \frac{E \cdot D^2}{0.05\ \frac{D}{V}}$$

Where:
Ie = effective intensity in candela (cd)
E = threshold of detection (lux)
D = nominal range (metres)
V = visibility (metres)

The figure below shows a table that applies Allard's Law and shows the correction for the two levels of background lighting.

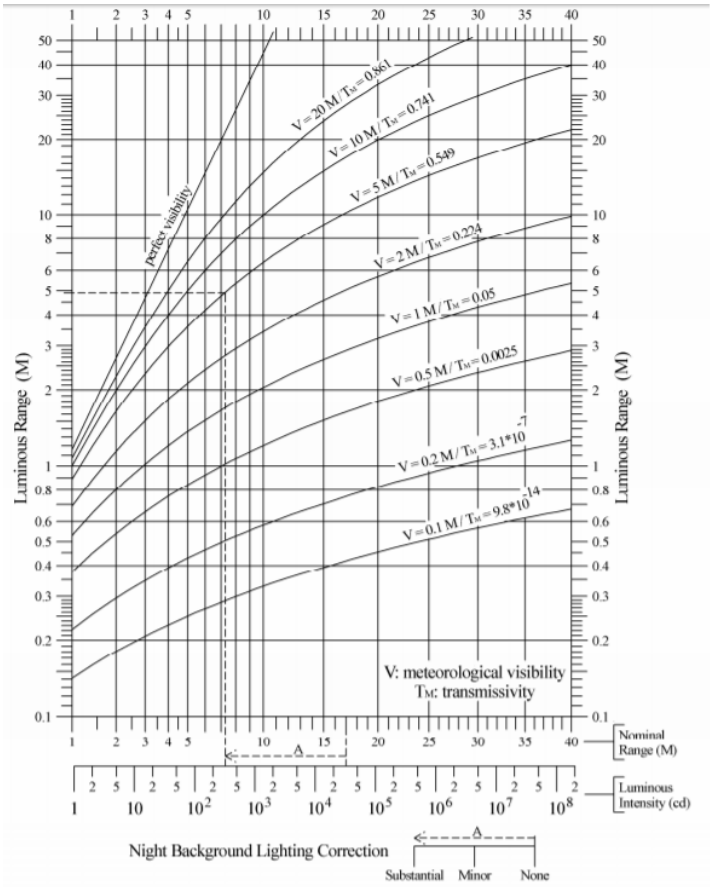


Figure 17: Relationship between Luminous Intensity and Range (Source: IALA)

The data in the graph above can be correlated to the intensity reduction that the *Informatieblad* permits. A 2,000 cd lamp at 90% reduction (i.e. effectively 200 cd) will be visible, at night, from 5 NM when the visibility is 10 km. With a 70% reduction, a 600-cd lamp, will be visible from 4 NM when the visibility is 5 km and 4.5 NM when the visibility is 8 km. However, experience from the Luchterduinen wind farm, located 12 NM from the shore, shows that lamps can be seen at greater distances than the IALA table report. The difference in this data is unknown, but it is assumed that the IALA data refers to the recognition of the lamp and not merely the perception of it. It is anticipated that obstacle lighting will be visible from a greater distance than can be theoretically calculated.

The United Kingdom CAA permits a reduction of 90% at 5 km visibility, a value that is less stringent that the Netherlands (and other countries that permit a reduction in intensity) does. Using the IALA data, a 200cd lamp will be visible from 2.8 NM when the visibility is 5 km. Research into the decision-making process in the United Kingdom was undertaken as part of this study. No safety case could be found, by the UK CAA, to justify the use of 90% reduction in 5 km visibility.

Considering the relationship between the range of the lights and the distance to shore, the current conditions permitted by the *Informatieblad* should ensure that the obstacle lighting on the three wind farm zones under consideration will not be clearly visible from the shore. The minimum distance from the shore to parts of the wind farm is 18 km; the 2,000 cd, 600 cd and 200 cd lamps will be visible from 8.3 km, 8.3 km and 9.26 km respectively.

It is not recommended to adopt the United Kingdom CAA's position on a further reduction in lamp intensity without additional justification. 2.8 NM at, say, 165 kt (the value used in the determination of the 900 metre turbine spacing requirement), permits a detection, reaction and manoeuvre time of 1 minute and 1 second. Whilst this is a greater distance and time from the obstacle referred to in the 900 metre turbine spacing requirement; there a 22 second margin was applied for detection, reaction and manoeuvre, the margin offered is, subjectively, considered to be insufficient.

8.1.4 Camouflaging the wind turbine blades and tower

The *Informatieblad* offers the developer a choice of four RAL-colour codes for painting the wind turbine blades and tower. Quoting only four colours appears more restrictive than the ICAO-standard upon which the guideline is based. Using RGB colour-codes, there are more shades of off-white available than just the four quoted in the *Infomatieblad*. It should be noted that there is a fifth RAL-colour included in the *Informatieblad*. This grey colour, RAL 7035, is excluded from this study as the *Informatieblad* requires a flashing white light in combination with this colour. International standards differ; for example, the USA (Ref: FAA AC 70/7460-1L) permits the use of any colour between RAL 9010 (pure white) and RAL 7035 (light grey) without the addition of any other lighting.

Regarding the addition of patterns or other colours to make the wind turbine less visible, a review of requirements from the Australia, Canada and UK show no additional guidance. The FAA, in paragraph 13.4.3 of the document mentioned above, explicitly states that blades may not be camouflaged "Blades or blade tips shall not be painted or manufactured in colors [sic] to camouflage wind turbines with the surrounding terrain". Gradient painted towers are also not permitted.

Camouflaging the wind turbine blades and towers would, in the context of the *Infomatieblad* and the practice in other States, be a novel solution. No scientific studies on the effect of camouflaging could be found. Various studies to suggest means of camouflaging the wind turbine blades and towers were reviewed. However, none of the studies reviewed could quantify in how far the visibility of the objects was reduced for observers on land. In addition, none of the studies reviewed addressed a minimum distance from which the objects would be visible to flight crew members.

For completeness, the following means to reduce the visibility of wind turbine blades and towers are most often quoted in the studies reviewed:

- Photo chromatic paint – applied to optimise the colour observed in differing light conditions
- Applicable of LEDs / lamps – counter illumination applied to reduce visibility. Scale model tests have been conducted in the USA on this (Mauk, Rhode Island School of Design, 2009 – 2013).
- Disruptive patterns – break the object up into smaller, more difficult to determine, objects. ROM3D (2016) has proposed the use of a checked pattern in pure white and pure black with a ratio 2/3 white and 1/3 black. The author reports that the checked pattern merges to a grey colour at a range of 18.5 km, but is visible as a two-colour object from about 5 km.

To70 is of the opinion that the minimum distance at which a camouflaged wind turbine would be clearly visible to a flight crew member in good visibility is 5 NM. This figure is derived from a number of sources, including requirements for VFR-flight and the dimensions of Helicopter Protection Zones in the North Sea. The tests conducted by ROM3D referred to here were witnessed in February 2017 at Maasvlakte. Appendix H to this report contains notes on the tests conducted.

Whilst the camouflage tests produced interesting results, the data set is not considered sufficient to make a judgement on a pattern or colour that is clearly visible under normal conditions at distances up to 5 – 8 km whilst being not visible from 15 – 20+ km. In the table above, for example, not enough combinations of weather conditions were encountered.

No studies containing relevant material were found. The UK's Maritime and Coastguard Agency included the following in its Maritime Guidance Note[18] entitled 'Offshore Renewable Energy Installations (OREIs) - Guidance on UK Navigational Practice, Safety and Emergency Response Issues; "Wind Turbine Generators (WTG) shall have high contrast markings (dots or stripes) placed at 10 metre intervals on both sides of the blades to provide SAR helicopter pilots with a hover-reference point". It is noted that whilst such markings are also applied in some other states, (including Belgium and Germany), their application in the guidance note is related to close-in operations and not aircraft approaching a wind farm site at speed.

An alternative approach to camouflaging the wind turbines and their blades is to look at research into the visibility of aeroplane propellers and helicopter rotors. Studies such as Improving U. S. Army Aircraft Propeller and tail Rotor Blade conspicuity with Paint, Crosley et al, 1972 and The Effect of Rotor Tip Markings on Judgements of Rotor Sweep Extent, Stuart and Hughes, 2010 have performed detailed study into which pattern is best visible under certain lighting conditions. The American study, Conspicuity Assessment of Selected Propeller and Tail Rotor Paint Schemes. Walsh et al, 1978, remains a well-quoted source. Its work was however limited to a range of only several metres from the object. None of the studies reviewed examined the question as to from how far away the markings became effective. It should also be noted that the studies reviewed were valid for objects rotating at high rpm (hundreds of revolutions per minute) when viewed from a short range.

Without detailed data on the visibility of the different option this report cannot complete the necessary risk assessment to make a proposal for an alternative to the ILT's *Infomatieblad*. The tests conducted are not considered rigorous enough to be used for a safety case. This is especially so when it is considered that camouflage is a new and untested application – in the sense of aviation. More detailed information should be gathered, as part of future research, to allow a clear set of data to be collated as to when the camouflaged wind turbine, both turning and still, becomes visible, considering:

- A more complete set of light conditions, and
- A model wind turbine that can be observed from above with water as the background.

This report makes no recommendation regarding the use of camouflage as a means to reduce the visibility of wind turbine blades and towers. Further research into the matter is recommended.

[18] MGN 371 (M+F), Maritime and Coastguard Agency, undated

8.2 Introduction to the risk matrix

A safety assessment is carried out in accordance with what To70 considers standard practice as derived from ICAO Annex 19. The assessment is the result of a desktop study using the available literature and expert judgement. No simulations or tests were performed. Regarding the proposal for using steady lamps to light the periphery of the wind farm parcels, a recommendation for simulation tests is made.

Risk Probability	Risk Severity: Catastrophic A	Major B	Hazardous C	Minor D	Negligible E
Frequent 5	5A	5B	5C	5D	5E
Occasional 4	4A	4B	4C	4D	4E
Remote 3	3A	3B	3C	3D	3E
Improbable 2	2A	2B	2C	2D	2E
Extremely Improbable 1	1A	1B	1C	1D	1E

Risk Category	Region / Risk Index	Criteria
I	Intolerable 5A, 5B, 5C, 4A, 4B, 3A	The consequence is unacceptable under the existing circumstances. The work or activity shall not proceed at all.
T	Tolerable 5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D 2A,2B,2C,1A	After reasonable mitigating measures have been taken to reduce the probability or the severity of the consequence, the work or activity may proceed upon endorsement from management.
A	Acceptable 3E, 2D, 2E, 1B, 1C, 1D, 1E	The consequence is extremely improbable or not severe enough to be of a concern.

The terms in the above table are defined as follows:

Severity	Meaning	Value
Catastrophic	Equipment destroyed Multiple deaths	A
Hazardous	A large reduction in safety margins, physical distress or a workload such that the operators cannot be relied upon to perform their tasks accurately or completely Serious injury Major equipment damage	B
Major	Serious incident; a significant reduction in safety margins, a reduction in the ability of the operators to cope with adverse operating conditions as a result of an increase in workload or as a result of conditions impairing their efficiency Injury to persons	C
Minor	Nuisance / Minor incident Operating limitations Use of emergency procedures	D
Negligible	Few consequences to safety	E

Likelihood	Meaning	Value
Frequent	Likely to occur many times (has occurred frequently (more than once a year))	5
Occasional	Likely to occur sometimes (has occurred infrequently (less than annually))	4
Remote	Unlikely to occur, but possible (has occurred rarely in the industry)	3
Improbable	Very unlikely to occur (not known to have occurred in the industry)	2
Extremely improbable	Almost inconceivable that the event will occur	1

Figure 18: Risk matrix - ICAO Annex 19, as amended by To70

The Netherlands does not publish a target level of safety for the boundary between what is 'tolerable' and 'intolerable' in civil aviation. As a quantitative study is not being made, no value was chosen for the study.

Three different aircraft types / type of operations are reviewed in isolation or in combination, depending on the sort of risk being considered:

- Low level fixed-wing;
- Helicopters, and
- Fast military traffic.

Aircraft speeds, the number of flight crew members and professionalism of the type of operations (i.e. private flights versus commercial and military operations) are factors that may lead to the traffic types being combined.

The assessment is documented in a Risk Assessment Form using the elements below.

Identified Hazards		**Consequences**		**Existing Mitigation Measures and Safety Risk Index**					**Further Action to Reduce Risk and Existing Safety Risk Index**			
S/N	Description	S/N	Description	S/N	Existing defences to control safety risk	Probability	Severity	Risk Category	Defences to reduce existing risks	Probability	Severity	Risk Category

Figure 19: Elements of the Risk Assessment Form

In the execution of the risk assessments, it was considered to be intolerable to have a residual risk that was categorised as 3A, 4A, 5A, 4B, 4A, or 3A (i.e. red risk). In addition, each risk should have no more than half of its residual risk categorised as 1A, 2A, 2B, 3B, 2C, 3C, 4C, 3D, 4D, 5D, 4E or 5E (i.e. yellow risk).

8.3 Risk elements for assessment

8.3.1 Fewer lamps

Safety issues related to the application of contour lighting include:

- Can a case be made for the use of steady lamps and not flashing lamps?
- What is the greatest distance between lamps that is acceptable?

The issue of contour lighting is evaluated against three specific situations:

- Lighting patterns for flight greater than 5 NM from the edge of a wind farm or flight 1,000 feet above the wind farm;
- Lighting patterns for flights that are less than 5 NM from the edge of a wind farm or fly low (less than 1,000 ft) over the wind farm, and
- Lighting patterns for flight within the wind farm.

Notwithstanding the above, a reduction in the number of lamps is not considered possible within 5 NM of a helideck. The 5 NM criteria here is related to the dimensions of the current HPZs in the North Sea. The distance has a close relationship to that required for an airborne radar approach.

As described elsewhere in this report, the lamps required by ICAO and the *Informatieblad* mid-way up the wind turbine's mast are considered essential for preserving the visual form of the wind farm. Reduction in their numbers is not proposed.

8.3.2 Less light intensity

The safety issues related to the use of shielding is, primarily, are the reduction illumination values adequate? An analysis is made here into the following:

- The UK's policy that permits a reduction to 10% when the visibility is 5,000 metres or greater during the twilight periods and at night;
- A reduction in the amount of light that is produced during the day, permitting a reduction to 30% when the visibility is 5,000 metres or greater, and
- Using a colour other than white for the wind turbine and its blades.

It should be noted that the lower light intensity is evaluated against two specific situations:

- Light intensity for flight greater than 5 NM (9,3 km) from the edge of a wind farm or flight 1,000 feet above the wind farm, and
- Light intensity for flights that are less than 5 NM from the edge of a wind farm or low flight (less than 1,000 ft) over the wind farm.

8.3.3 Shielding the lamps

As the shielding of the lamps is not considered to be a practical solution, no analysis is made in this report into the shielding of lamps.

8.3.4 Detection systems

Detection systems permit the lamps to be switched off during periods when no are vicinity.
Issues related to the use of a detection system include:

- Fail-safe mechanism – do the lamps switch on when the detection system fails?
- Do the lamps only switch on when low level traffic is in the vicinity?
- Is the detection system set up to ensure that low level traffic in the vicinity is detected all around the wind farm?
- Is such a system acceptable to maritime users?

8.3.5 Infra-red marking

Not evaluated in this report. See paragraph 7.6.

8.4 Risk assessment forms

The following pages contain the risk assessment forms. The mitigating measures, where acceptable, are collated into possible solutions in chapter 9 below.

8.4.1 Fewer lamps

Fewer lamps - Can a case be made for the use of steady lamps and not flashing lamps?

Identified Hazards		**Consequences**		**Existing Mitigation Measures and Safety Risk Index**					**Further Action to Reduce Risk and Existing Safety Risk Index**			
S/N	Description	S/N	Description	S/N	Existing defences to control safety risk	Probability	Severity	Risk Category	Defences to reduce existing risks	Probability	Severity	Risk Category
1	Lamps not readily identifiable at distance	C 1.1	Steady lamps are not distinguishable in the same way that flashing lamps are	M 1.1	Nil	4	C	**4C**	Ensure that any reduction in intensity does not impair ability of flight crew to see lamps at 900 metre intervals	3	C	**3C**
		C.1.2	Aircraft operates too close to wind farm (civilian traffic)	M.1.2		3	C	**3C**	Improve charting to better identify wind farm	1	C	**1C**
		C.1.3	Aircraft operates too close to wind farm (military jet)	M.1.3		4	C	**4C**	Publish location of the 'corners' of the wind farm zones in digital obstacle database	N/A		
		C.1.4	Aircraft strikes obstacle (civilian traffic)	M.1.4		2	A	**2A**	KNVvL[19] to provide indoctrination to GA-pilots	1	A	**1A**
		C.1.5	Aircraft strikes obstacle (military jet)	M.1.5		2	A	**2A**	Prohibit fast jet ops below 1,200 feet above North Sea within 5 NM ((9.3 km) of wind farm zones	N/A		
	Continued over											

[19] Royal Netherlands aeronautical association

Identified Hazards		Consequences		Existing Mitigation Measures and Safety Risk Index					Further Action to Reduce Risk and Existing Safety Risk Index			
S/N	Description	S/N	Description	S/N	Existing defences to control safety risk	Probability	Severity	Risk Category	Defences to reduce existing risks	Probability	Severity	Risk Category
2	Combination of lamps is confusing – leads to disorientation – close in	C.2.1	Crew member disorientation (single-engine, single pilot operations)	M.2.1	Nil	3	B	**3B**	Introduce restricted airspace to deter single-engine from the flying above and around the wind farm zones	N/A		
		C.2.2	Crew member disorientation (multi-pilot operations)	M.2.2		3	C	**2C**	Improve charting to better identify wind farm	2	C	**2C**
		C.2.3	Aircraft temporary loss of control	M.2.3		2	B	**2B**	Publish location of the 'corners' of the wind farm zones in digital obstacle database	1	B	**1B**
		C.2.4	Aircraft total loss of control	M.2.4		1	A	**1A**	Provide information to flight crews via Aeronautical Information Circular (AIC) on risks of potential disorientation	1	A	**1A**

Fewer lamps – Is 1,200 metres between lamps a greater distance than is acceptable for contour lighting?

Identified Hazards		Consequences		Existing Mitigation Measures and Safety Risk Index					Further Action to Reduce Risk and Existing Safety Risk Index			
S/N	Description	S/N	Description	S/N	Existing defences to control safety risk	Probability	Severity	Risk Category	Defences to reduce existing risks	Probability	Severity	Risk Category
3	Outline of wind farm is unclear to flight crews – close-in	C.3.1	Aircraft operates too close to wind farm (civilian traffic)	M.3.1	Nil	3	C	**3C**	Improve charting to better identify wind farm	1	C	**1C**
		C.3.2	Aircraft operates too close to wind farm (military jet)	M.3.2		4	C	**4C**	Publish location of the ‘corners’ of the wind farm zones in digital obstacle database	N/A		
		C.3.3	Aircraft strikes obstacle (civilian traffic)	M.3.3		1	A	**1A**	KNVvL to provide indoctrination to GA-pilots	N/A		
		C.3.4	Aircraft strikes obstacle (military jet)	M.3.4		1	A	**1A**	Prohibit fast jet ops below 1200 feet above North Sea within 5 NM of wind farm zones	N/A		
4	Distance between turbines cannot be established when operating along boundary	C.4.1	Aircraft operates too close to wind farm (civilian traffic)	M.4.1	Nil	4	C	**4C**	Ensure that any reduction in intensity does not impair ability of flight crew to see lamps at 900 metre intervals	2	C	**2C**
		C.4.2	Aircraft operates too close to wind farm (military jet)	M.4.2		5	C	**5C**	Publish location of the ‘corners’ of the wind farm zones in digital obstacle database	N/A		
		C.4.3	Aircraft strikes obstacle (civilian traffic)	M.4.3		2	A	**2A**	Introduce restricted airspace to deter single-engine from the flying above and around the wind farm zones	1	A	**1A**
		C.4.4	Aircraft strikes obstacle (military jet)	M.4.4		2	A	**2A**	Prohibit fast jet ops below 1,200 feet above North Sea within 5 NM of wind farm zones	N/A		
	Continued over											

Identified Hazards		Consequences		Existing Mitigation Measures and Safety Risk Index					Further Action to Reduce Risk and Existing Safety Risk Index			
S/N	Description	S/N	Description	S/N	Existing defences to control safety risk	Probability	Severity	Risk Category	Defences to reduce existing risks	Probability	Severity	Risk Category
5	Distance between turbines cannot be established when operating inside the wind farm	C.5.1	GA traffic strikes obstacle	M.5.1	Nil	4	A	**4A**	Publish location of the 'corners' of the wind farm zones in digital obstacle database Provide additional lamps in areas where it is planned to operate with helicopters during the night period. Introduce restricted airspace to deter single-engine from the flying above and around the wind farm zones Prohibit fast jet ops below 1,200 feet above North Sea within 5 NM of wind farm zones	N/A		
		C.5.2	Helicopter other than SAR strikes obstacle	M.5.2		3	A	**3A**		2	A	**2A**
		C.5.3	SAR helicopter strikes obstacle	M.5.3		2	A	**2A**		2	A	**1A**
		C.5.4	Coastguard (fixed-wing) aircraft strikes obstacle	M.5.4		3	A	**3A**		N/A		
		C5.5	Military jet aircraft strikes obstacle	M.5.5		4	A	**3A**				

8.4.2 Less light intensity

Less light intensity - can the UK's policy for light intensity be adopted in the Netherlands North Sea?

Identified Hazards		**Consequences**		**Existing Mitigation Measures and Safety Risk Index**					**Further Action to Reduce Risk and Existing Safety Risk Index**			
S/N	Description	S/N	Description	S/N	Existing defences to control safety risk	Probability	Severity	Risk Category	Defences to reduce existing risks	Probability	Severity	Risk Category
6	Lower light intensity is insufficient for flight more than 5 NM from the edge of a wind farm or flight 1.000 feet above the wind farm	C.6.1	GA traffic strikes obstacle	M.6.1	Nil	2	A	**2A**	Improve charting to better identify wind farm Publish location of the 'corners' of the wind farm zones in digital obstacle database to better facilitate RNAV operations (Area Navigation)	2	A	**2A**
		C.6.2	Helicopter strikes obstacle	M.6.2		2	A	**2A**		2	A	**2A**
		C.6.3	Coastguard (fixed-wing) aircraft strikes obstacle	M.6.3		2	A	**2A**		2	A	**2A**
		C.6.4	Military jet aircraft strikes obstacle	M.6.4		2	A	**2A**		2	A	**2A**
7	Lower light intensity is insufficient for flight less than 5 NM from the edge of a wind farm or for low flight (i.e. below 1.000 feet) above the wind farm	C.7.1	GA traffic strikes obstacle	M.7.1	Nil	2	A	**2A**	Improve charting to better identify wind farm Publish location of the 'corners' of the wind farm zones in digital obstacle database to better facilitate RNAV operations Increase light intensity to 100% when SAR-operations are in progress Introduce restricted airspace to deter single-engine from the flying above the wind farm zones	N/A		
		C.7.2	SAR helicopter strikes obstacle	M.7.2		3	A	**3A**		2	A	**2A**
		C.7.3	Helicopter other than SAR strikes obstacle	M.7.3		2	A	**2A**		2	A	**2A**
		C7.4	Coastguard (fixed-wing) aircraft strikes obstacle	M.7.4		2	A	**2A**		2	A	**2A**
		C7.5	Military jet aircraft strikes obstacle	M.7.5		2	A	**2A**		N/A		

Identified Hazards		Consequences		Existing Mitigation Measures and Safety Risk Index					Further Action to Reduce Risk and Existing Safety Risk Index			
S/N	Description	S/N	Description	S/N	Existing defences to control safety risk	Probability	Severity	Risk Category	Defences to reduce existing risks	Probability	Severity	Risk Category
									Prohibit fast jet ops below 1,200 feet above North Sea within 5 NM of wind farm zones			

Less light intensity - can a colour other than white be applied to the tower and the turbine blades?

Identified Hazards		Consequences		Existing Mitigation Measures and Safety Risk Index					Further Action to Reduce Risk and Existing Safety Risk Index			
S/N	Description	S/N	Description	S/N	Existing defences to control safety risk	Probability	Severity	Risk Category	Defences to reduce existing risks	Probability	Severity	Risk Category
8	Outline of wind farm is unclear to flight crews – close-in	C.8.1	Aircraft operates too close to wind farm (civilian traffic)	M.8.1	Nil	3	C	**3C**	Additional research work into camouflage is required before this risk can be fully mitigated			
		C.8.2	Aircraft operates too close to wind farm (military jet)	M.8.2		4	C	**4C**				
		C.8.3	Aircraft strikes obstacle (civilian traffic)	M.8.3		1	A	**1A**				
		C.8.4	Aircraft strikes obstacle (military jet)	M.8.4		1	A	**1A**				

8.4.3 Shielding the lamps

Shielding the lamps – general risk assessment

Identified Hazards		**Consequences**		**Existing Mitigation Measures and Safety Risk Index**					**Further Action to Reduce Risk and Existing Safety Risk Index**			
S/N	Description	S/N	Description	S/N	Existing defences to control safety risk	Probability	Severity	Risk Category	Defences to reduce existing risks	Probability	Severity	Risk Category
9			The risks for this scenario are considered to be the same as for the first two risks for using steady lamps and not flashing ones (S/N 1 & 2). The tables are not repeated here. As stated elsewhere in this report, the technical feasibility of a light shield has yet to be demonstrated.									

8.4.4 Detection systems

Detection systems – do the lamps switch on every time they are as required and not at other times?

Identified Hazards		**Consequences**		**Existing Mitigation Measures and Safety Risk Index**					**Further Action to Reduce Risk and Existing Safety Risk Index**			
S/N	Description	S/N	Description	S/N	Existing defences to control safety risk	Probability	Severity	Risk Category	Defences to reduce existing risks	Probability	Severity	Risk Category
10	Lamps do not switch when required to do so	C10.1	Unlit obstacle that any aircraft can strike if the wind farm is entered.	M10.1	Nil	3	A	**3A**	Fail-safe engineering required to ensure high level of reliability in switching systems & swift control room actions to notify LVNL of power failures.	1	A	**1A**
11	Lamps switch on when other traffic (i.e. not low-level) is ovrhead	C11.1	Confusion for overflying aircraft	M.11.1		4	D	**4D**	Detection systems shall be calibrated to not activate when traffic is above FL 055.	2	E	**2E**
12	Is such a system acceptable to maritime users?	C12.1	Confusion for maritime users	M.12.1		4	E	**4E**	Awareness material to be published in Nautical Almanac	3	E	**3E**
13	Is it acceptable to use a detection system and apply the reduced intensity setting for lamps?	C.13.1	Reduced reaction time by flight crew	M.13.1	Nil	3	B	**3B**	Improve charting to better identify wind farm, including unique marking for the system in use	3	E	**3E**
		C.13.2	Flight crew confusion / loss of situational awareness	M.13.2		4	E	**4E**	Publish location of the 'corners' of the wind farm zones in digital obstacle database	3	E	**3E**

8.4.5 Infra-red marking

Infra-red marking

Identified Hazards		**Consequences**		**Existing Mitigation Measures and Safety Risk Index**					**Further Action to Reduce Risk and Existing Safety Risk Index**			
S/N	Description	S/N	Description	S/N	Existing defences to control safety risk	Probability	Severity	Risk Category	Defences to reduce existing risks	Probability	Severity	Risk Category
14			Not evaluated in this study									

9 Conclusions and Recommendations

9.1 Introduction

On average, a visibility of greater than 20 km was noted from the Dutch coastline at between 25 and 38 percent of the time per 24-hour period in the summer months. For this study a number of possible solutions were investigated to reduce the visibility of wind farm zones from the coast:

- Fewer lamps;
- Lower light intensity;
- Painting the tower and turbine blades off-white or grey;
- Shielding the lamps;
- Detection systems, and
- Infra-red systems.

The following section presents the feasibility of all assessed solutions, based on the risk assessment. The solutions are intended, unless stated otherwise, to be applied to those offshore wind farm sites where a reduction in light levels is desirable from the point of view of coastal residents. That is to say that the study assesses generic solutions and models that could be applied to the above proposed wind farm sites and other, similar, offshore sites in the future.

9.2 Fewer lamps

The following options were explored to reduce the number of lamps:

1. Flashing contour lighting (with max 900 metres distance between lights) following ILT *Informatieblad;*
2. Continuous lighting with a 1,200 metre grid configuration, following FAA Advisory Circular.
3. Combination of 1 & 2: continuous burning contour lighting the following configurations:
    - Variation 1: Contour lighting of all parcels
    - Variation 2: Contour lighting of the entire wind farm
    - Variation 3: Contour lighting of parcels north and south of channel
    - Variation 4: Contour lighting of sites I & II, and sites II, IV & V.

All four variations reduce the number of lamps required. Option 1 and 2 are already permitted without additional review. All alternative variations of option 3 need to be assessed by ILT prior application. Continuous burning contour lighting, using a slightly different interpretation to that proposed in the ILT's *Informatieblad* has been proposed as a safe and compliant solution. A reduction of the number of lamps can be achieved by this between 27 and 73%. The different assessed variations all appear to be possible, but variations 1 and 2 seem to give the fewest number of sight lines that do not meet the modified 900 metre distance between lamps that To70 proposes, but this does not take into account yet the maximum distance lamps shall be located behind each other.

For these alternative proposals, it is argued that a maximum of 900 metre between lamps should be in line of sight. That means that, when a pilot approaches the wind farm, nearby or further away, a maximum distance between lamps shall be 900 metre. Based on the currently available information, it is not yet possible to define the maximum distance between lamps to guarantee a 900-metre line of sight. Therefore, a study, for instance by means of a simulation study, is recommended to define the optimal configuration to assure the required 900-metre line of sight on the horizon in addition to the regular considerations for the design of wind farm sites (e.g. prevailing wind direction and geology).

Based on the material analysed in this study, the preferred solution for the onshore reduction of the light intensity of obstacle lighting on offshore wind turbines is as follows:

1. Implement a network of contour lighting such that each chosen Site or Sites has/have a continuous boundary of lighting. The exact configuration is the choice of the applicant but it should be recalled that the distance between the lamps that are illuminated may be as great as 1,200 metres provided that the great majority of the fields of sight include lamps – be they at the near or far edge of the site – that are less than 900 metres apart.
2. Contour lighting based on lamps that project their light at distances equal to no more than 900 metres. The lights are thus not actually 900 metres apart.
3. Inner lamps, if not required to help achieve above, will not be required.
4. Those wind turbines with lamps on the nacelle will be required to have them placed mid-way on the mast as per ICAO / *Informatieblad*.

The proposal will, for the Borssele Wind Farm Zone, reduce the number of lamps to be illuminated. The application of contour lighting should be combined with the following measures.

- If helicopter search and rescue operations can be expected to occur within the wind farm, all wind turbines shall have lamps installed and a command and control protocol is required to allow all the lamps to be illuminated at short notice when helicopter search and rescue operations require this. This does not restrict the practice of illuminating fewer lamps as described in this report.
- Regardless of the possible reduction, all wind turbines within a range of 5 NM of a helideck shall be illuminated when night operations take place.
- The creation of data for an obstacle database is essential. Improved charting is also required. Restricted airspace as per NL AIP ENR 5.1, para 7.3 and EASA Part SERA 3145 should be created around each wind farm to improve awareness of the location of the wind farm zones. The restricted airspace is recommended to have it boundaries 5 NM (9.3 km) around the wind farm and be vertically defined from sea level to FL 055 (the Class A airspace ceiling in the North Sea).
- To further improve awareness of the location of the wind farm zones, safety awareness material should be created for both general aviation pilots and commercial crew members.
- Military fast jet operation should be avoided below 1,200 ft when within 5 NM of the wind farm zones.

Wind farm design software (e.g. Openwind, WindFarm and WindFarmer) can be used to apply the rules mentioned above and determine a compliant lighting plan.

The proposals here are the result of a desktop study. They are considered, assuming accurate preparation by wind farm designers, to be achievable and safe. The practicality of the proposals (e.g. confirm that reduced visibility does not invalidate the proposed model) can be tested in a Level C/D simulator. Data from such a test will assist in the acceptance of an application to the ILT.

9.3 Lower light intensity

Reduction of the light intensity to a level lower than that permitted by ILT *Informatieblad,* as per the practice currently permitted in the United Kingdom, is not supported by sufficient data to recommend its use. Additional study is required before this solution can be accepted.

It should be noted that a reduced light intensity may not be compatible with every combination of contour lighting. Applicants should take care to ensure that a reduction plan is developed in conjunction with the exact pattern of the contour that is to be lit.

9.4 Painting the tower and turbine blades off-white, grey or patterned;

Painting the tower and turbine blades with patterns or in colours other than those referred to in the *Informatieblad* is not supported by sufficient data to allow a risk assessment to be performed. The approach appears to be feasible but further research is required into the use of colours and patterns to camouflage wind turbines so that they are clearly visible at distances up to 5 – 8 km whilst not being visible from, say, 15 – 20+ km. This matter could include more colours than the RAL-colours adopted in the *Informatieblad*; more shades of white, off-white and light grey exist when RGB-codes are considered. Such research requires a combination of input based on aviation best practices and visual acuity science. The research should include any differences between the onshore and offshore use of such a system.

9.5 Shielding the lamps;

The shielding of lamps as a means to reduce the perception of the lamps from the shore has not been studied. ILT's *Informatieblad* notes that an acceptable level of shielding is not likely to have any significant effect on reducing the visibility of the lamp from a large distance. As the merits of shielding the lamps is not proven, this measure is not considered viable.

9.6 Detection systems

Aircraft detection systems are a possible solution that will allow lamps only to be activated when aircraft are near the wind farm. The current study does not take a definitive position on the use of detection systems, based on radar or other means, that can be used to activate obstacle lamps when aircraft are in the vicinity. The technology appears to be mature enough to allow its use. Further work is recommended to produce an analysis that will allow the ILT to take a position on the use of this technology, in case the application of detection systems is considered.

9.7 Infra-red systems

Infra-red systems – the use of infra-red applications has not been studied as not all aviation users are able to make use of this technology. for instance, helicopter search and rescue operations within the wind farm may be conducted without night vision googles requiring infra-red to be an option that is 'in addition to' and 'instead of'.

Appendix A: Conversion Table Metres to Miles

As Meters and Nautical Miles (NM) are both used in this report, the following table is provided to show the conversion of the values.

Metres	Nautical Miles
500	0.27
1,000	0.54
2,000	1.0799
3,000	1.6199
5,000	2.6998
10,000	5.3996
20,000	10.7991

Nautical Miles	Metres
0.5	926
1	1,852
2	3,704
3	5,556
5	9,260
10	18,520
20	37,040

The conversion is:

- 1 metre = 0.000539956 NM
- 1 NM = 1,852 metres

Appendix B Maps

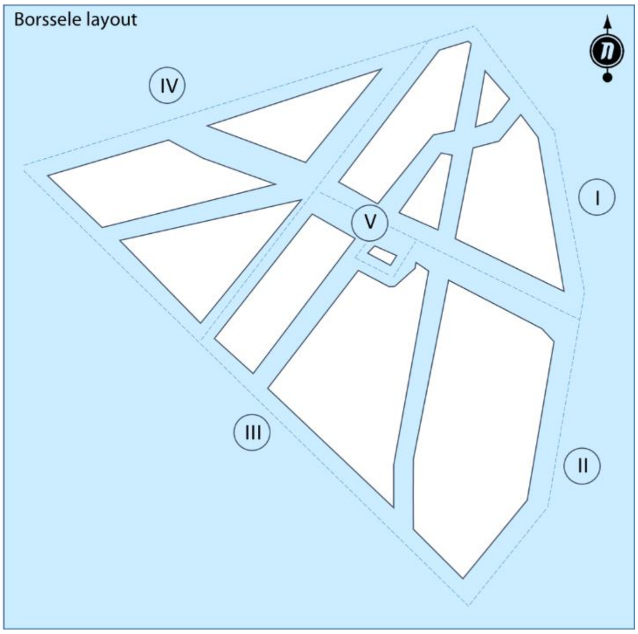


Figure A-1: Wind farm Borssele (based on GIS data from RVO)

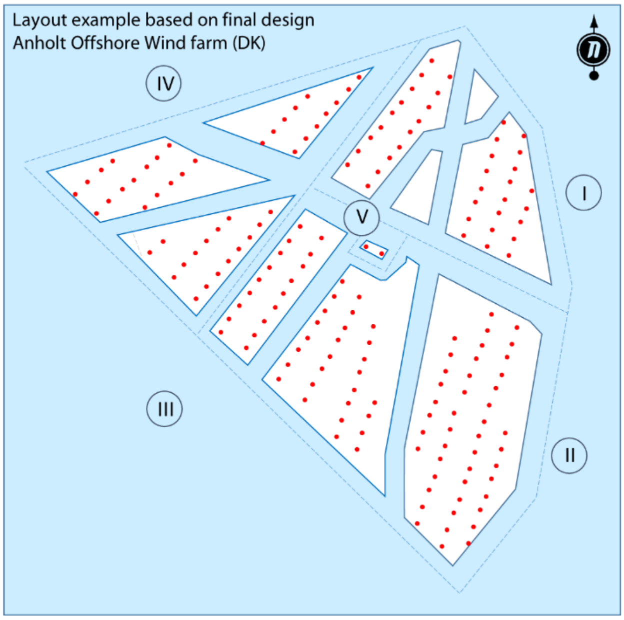


Figure A-2: Theoretical population for wind farm Borssele considering prevailing wind

The figure above is a simple representation of a possible, theoretical representation of how the Borssele Wind Farm Zone could be populated with wind turbines considering the prevailing wind direction: 220 degrees.

The layout of the wind turbines has not taken sea floor surface conditions into account and is derived from information provided by Dong Energy regarding wind turbine layout at the Anholt wind farm in Denmark (see figure below).

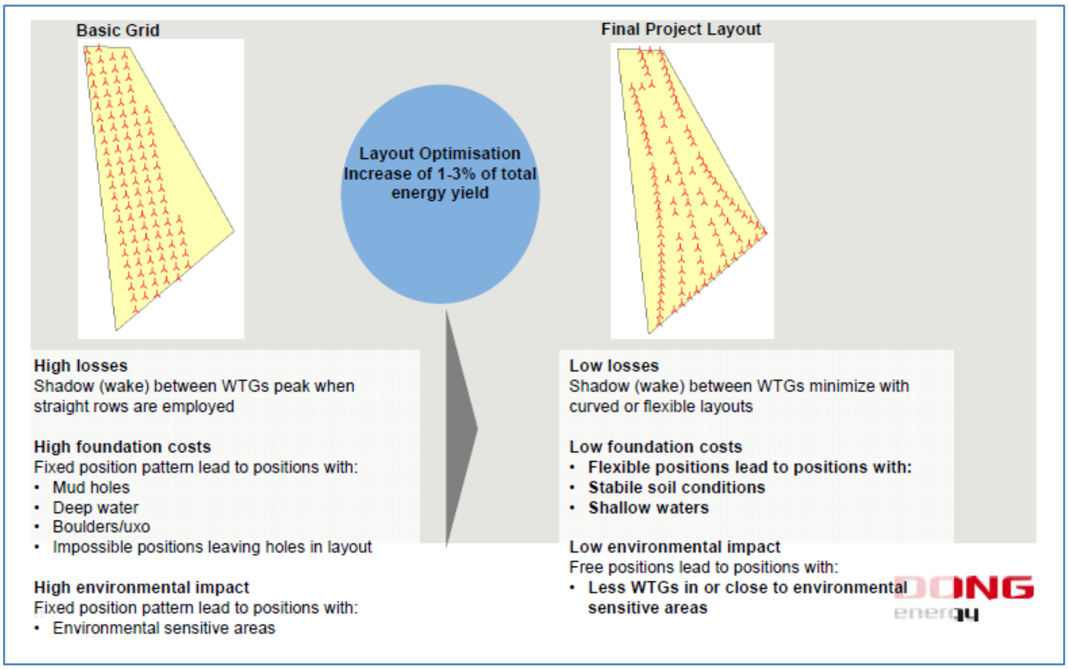


Figure A-3: Layout optimalisation of Anholt offshore wind farm (Source: Dong Energy, via NWEA)

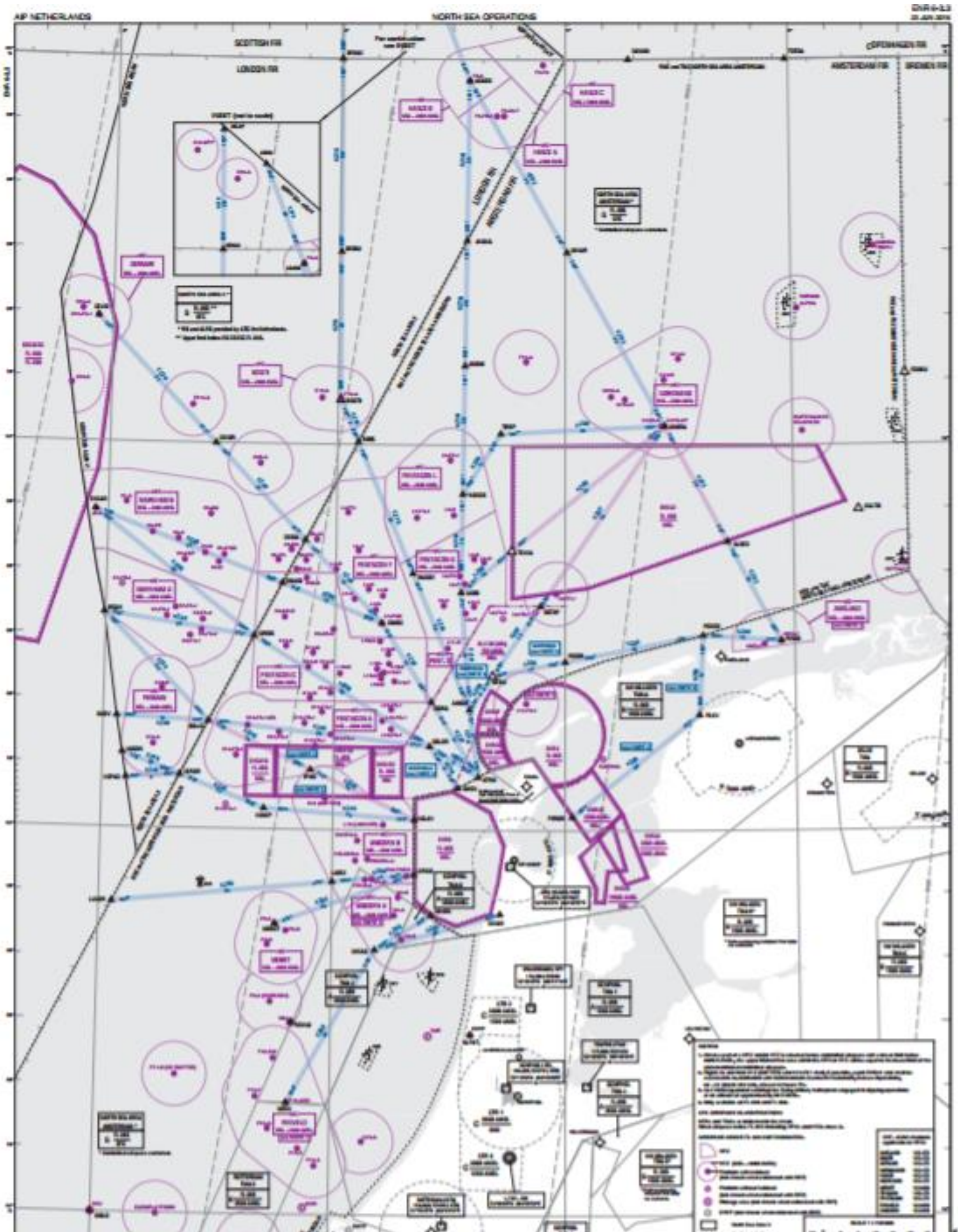


Figure A-4: NL AIP Chart 6.3.3 North Sea operations; extract from AIP (Source: LVNL)

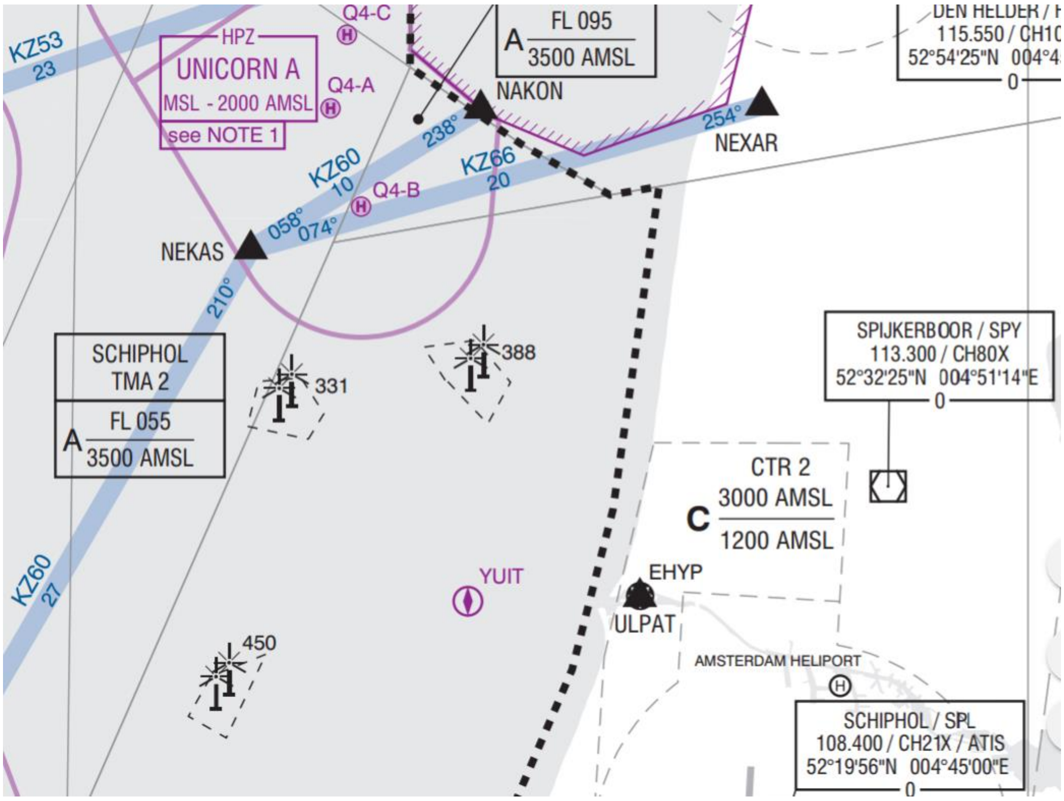


Figure A-5: Detail view of NL AIP Chart 6.3.3 showing existing wind farm zones (Source: LVNL)

Appendix C Description of flight operations in the North Sea

Following interviews and the exchange of information with aviation users, the following description of flight operations in the North Sea that can be expected to be conducted in and around wind farm zones has been prepared.

The aviation users that operate below the traffic described above include:

- Helicopter operators operating in support of oil & gas work and supporting the wind farm zones;
- Coastguard flights with both fixed-wing aeroplanes and helicopters;
- Military flights with both fixed-wing aeroplanes and helicopters, and
- General aviation aircraft operating en-route at low-level under both VFR (Visual Flight Rules) and IFR (Instrument Flight Rules).

Helicopter operators operating in support of oil & gas work

The users with the greatest number of flights at low level above the North Sea are the civilian helicopter operators. Helicopters operate to and from oil & gas rigs with staff and equipment. In addition, helicopters can be used to service wind turbines inside wind farm zones. Published North Sea helicopter routes in Dutch airspace have vertical limits between 1,500 and 5,500 feet (some have an upper limit of 6,500 feet). Flight operations prior to the commencement of an approach are typically flown at an altitude of around 1,500 feet. Helicopter cruise speeds for those operating above the North Sea are typically in a range between 130 to 150 knots. The two main helicopter airports in the area are at Den Helder and Oostende (Belgium). Flights can take place at day or night under VFR or IFR rules with equipment and crews capable of executing RNAV (including GPS) procedures. A limiting factor for flight operations is the temperature. If the freezing level (the altitude at which the temperature is 0 degrees C) is below 3,000 feet, operations may be restricted.

Coastguard flights

Coastguard flight take place with helicopters and with fixed wing aeroplanes[20]. By the nature of their work, coastguard flights can take place anywhere above the North Sea. The weather limitations for coastguard fights are, by nature of their work, lower than for other users. In total, according to data provided by the Coastguard, 2,000 – 2,500 flights per year operate above the North Sea. The following section describes the operations per aircraft type:

- Fixed wing aircraft operations

  The fixed wing aeroplanes used (at present a Dornier 228-112 aeroplane) cruise at 170 to 190 knots. Flights take day and night place above the entire North Sea, predominantly under visual flight rules with equipment and crews capable of executing RNAV (including GPS) procedures. On average once a week a flight takes place with the Dornier above the North Sea. Flights take place more frequent near wind farm zones Hollandse Kust (noord) and (zuid), than Borssele, as most flying routes are located near the former wind farm zones. During the day, the flying altitude ranges between 100 feet and 1,000 feet. During the night the altitude is mainly above 1,000 ft, but incidentally 500 feet as well.

[20] Source: H.J.W. Hollanders, *Kustwacht, bureau Operationele Planning*

- Helicopter search and rescue operations.
  The helicopters used at present are the Dauphin AS 365 (for search and rescue activities by, performed by Noordzee Helikopters Vlaanderen (NHV). Flights take place day and night above the entire North Sea, predominantly under visual flight rules with equipment and crews capable of executing RNAV (including GPS) procedures. On average 1 to 3 times a week a flight takes place above the North Sea. Flying altitude ranges between 50 feet and 2,000 feet. In contrast to the Dornier, flights are to be expected near and through the wind farm zones. Flying speed ranges between 70 kts (search activities) and 150 kts (maximum speed). As from April 2017, ships up to 24-metre-tall have free passage in certain wind farm zones during the hours of daylight. This means that search and rescue activities are to be expected in and above the wind parks; predominantly during the day as a rescue operation that extends into the night time period cannot be discounted. At present, NHV does not use night vision googles at night. If night vision googles were to be introduced by NHV or a future search and rescue operator, it should be noted that in the nature of search and rescue operations, once a rescue is underway, searchlights or the lights of boats may require the rescue portion of the flight to be conducted visually and without googles.

Police flights
The police and air ambulance organisations in the Netherlands both use helicopters. The only police flights that take place over the North Sea are conducted on behalf of Rijkswaterstaat. These flights are inspection and enforcement flights that take place with the police helicopter AW139. Flights may be carried out day and night, mainly above an altitude of 500 feet.

General aviation
The last group of users is the general aviation community. Small single and twin engine aeroplanes may operate above the North Sea at day or night under IFR or VFR rules. The use of GPS (both certified and un-certified systems) is common. Typical cruise speeds will vary between 95 and 150 knots. Although no specific data was sought. After discussions with Royal Dutch Aeroclub (KNVvL), it is established that there are only a limited number of such flights that operates over the area currently planned for the wind farm at Borssele during flights to and from the United Kingdom. Such flights may, under VFR, operate at any altitude above 500 feet. However, this requirement applies to an altitude above any obstacle; i.e. 500 feet above a wind turbine. In addition, the pilot in command is required to operate at an altitude that is sufficiently high to glide clear of any obstacle in the event of an engine failure. 3,500 to 5,500 feet are typical altitudes for such flights. It has not been possible to obtain information on the numbers of such flights that take place each year. An estimate of less than 1,000 flights per year seems plausible.

Air ambulance flights
The air ambulance organisation, MAA, makes use of helicopters. MAA has stated that they do not currently operate to oil and gas facilities in the North Sea. They do not foresee a need to operate in the vicinity of the wind farm zones in the future.

Military flights
Military traffic above the North Sea can range from helicopters that have a similar profile to the commercial operators to low-level high-speed fighter operations. These may be below 1,000 feet and at

speeds above 250 knots. According to information publically available, the military prefers to avoid areas of other traffic and obstacles whenever possible.

Civil aviation to and from Schiphol or Rotterdam Airport

In the context of this study, low level means at or below about 6,000 feet. This discriminator is intended to exclude those airline flights descending into or climbing out from either Schiphol Airport or Rotterdam Airport. To confirm that these flights could be excluded, To70 has reviewed ADS-B for flights[21] above the North Sea along a line from, approximately, the north of the Hollandse Kust (noord) wind farm to the south of the Borssele wind farm (see Figure B-1). The data has been plotted onto a heat map to show the amount of traffic at different altitudes. Figures B-2 and B-3 show that almost all traffic for these two airports is above at least 13,000 feet altitude on passing the wind farm zones addressed in this study. The Schiphol traffic is concentrated at two altitudes; 13,000 feet (ca. 4,000 metres) and 23,000 feet (ca. 7,000 metres) above the wind farm zones. The Rotterdam traffic is concentrated at about 17,000 feet (ca. 5,200 metres).

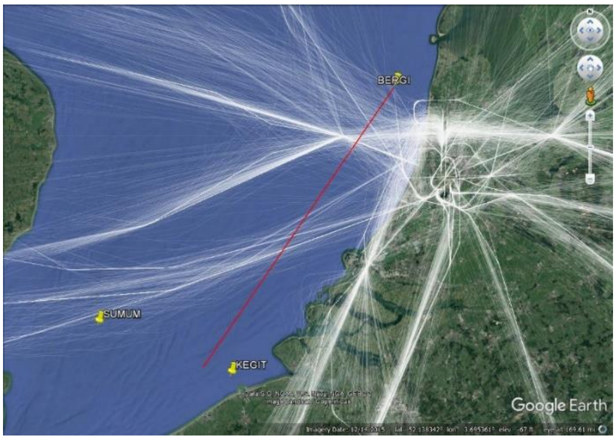


Figure B-1 Traffic in and out of Schiphol Airport (top) and Rotterdam Airport (bottom)

[21] 5,000 flights for Schiphol and 2,500 flights for Rotterdam in the period between 1 January 2016 to 31 October 2016 were used for the production of the heat maps.

The traffic that was measured passing the red line in the above two diagrams was analysed to review the altitude at which the flights intersected the line. The results of that analysis are shown in two heat maps, one for traffic in and out of Schiphol Airport and one for the traffic in and out of Rotterdam Airport. Where, in the figures below, there is no traffic present, the image is dark blue. The intensity of the traffic is shown in a scale of colours from light blue through white, yellow and red.

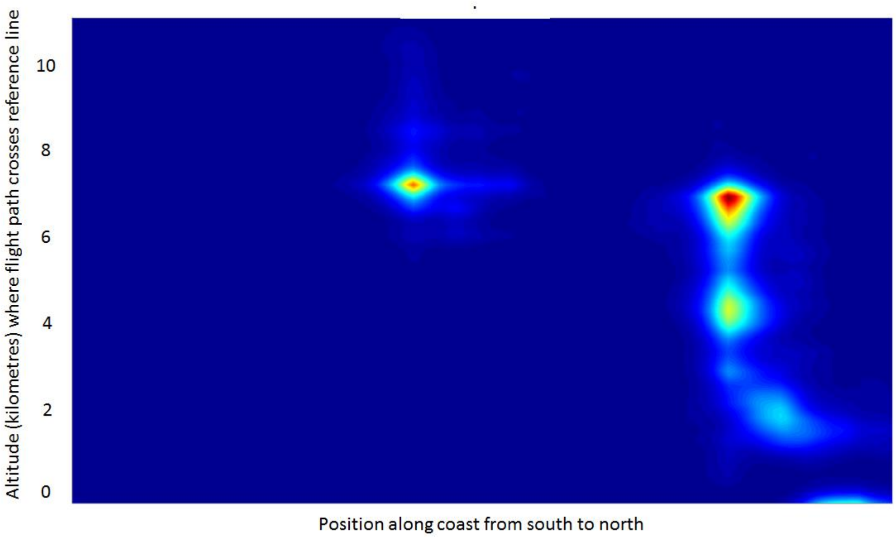


Figure B-2 Heat map for approaches to and departures from Schiphol Airport

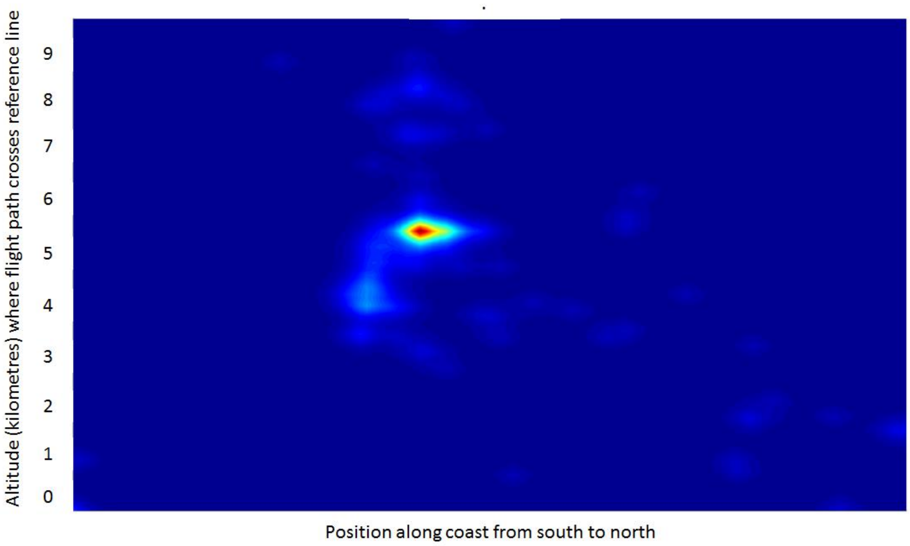


Figure B-3 Heat map for approaches to and departures from Rotterdam Airport

Appendix D Extracts from ICAO Annex 14, Volume I, 7th edition

4.3 Objects outside the obstacle limitation surfaces

4.3.1 Recommendation.— Arrangements should be made to enable the appropriate authority to be consulted concerning proposed construction beyond the limits of the obstacle limitation surfaces that extend above a height established by that authority, in order to permit an aeronautical study of the effect of such construction on the operation of aeroplanes.

4.3.2 Recommendation.— In areas beyond the limits of the obstacle limitation surfaces, at least those objects which extend to a height of 150 metres or more above ground elevation should be regarded as obstacles, unless a special aeronautical study indicates that they do not constitute a hazard to aeroplanes.

Note.— This study may have regard to the nature of operations concerned and may distinguish between day and night operations.

6.1.2 Objects outside the lateral boundaries of the obstacle limitation surfaces

[To70 comment: 6.1.2 contains three tables, Table 6-1, 6-2 and 6-3 – not reproduced here - that describe the characteristics of obstacle lamps, and their light distribution].

6.1.2.1 Recommendation.— Obstacles in accordance with 4.3.2 should be marked and lighted, except that the marking may be omitted when the obstacle is lighted by high-intensity obstacle lamps by day.

6.1.2.2 Recommendation.— Other objects outside the obstacle limitation surfaces should be marked and/or lighted if an aeronautical study indicates that the object could constitute a hazard to aircraft (this includes objects adjacent to visual routes e.g. waterway, highway).

[To70 comment: requirements also exist for the lighting of objects with a height less than 45 metres above ground level and those with a height 45 metres to a height less than 150 metres above ground level. They are not summarized here].

……

6.2.3.28 Recommendation.— High-intensity obstacle lamps, Type A, should be used to indicate the presence of an object if its height above the level of the surrounding ground exceeds 150 metres and an aeronautical study indicates such lights to be essential for the recognition of the object by day.

6.2.3.29 Where high-intensity obstacle lamps, Type A, are used, they shall be spaced at uniform intervals not exceeding 105 metres between the ground level and the top light(s) specified in 6.2.3.10, except that where an object to be marked is surrounded by buildings, the elevation of the tops of the buildings may be used as the equivalent of the ground level when determining the number of light levels.

6.2.3.30 Recommendation.— Where, in the opinion of the appropriate authority, the use of high-intensity obstacle lamps, Type A, at night may dazzle pilots in the vicinity of an aerodrome (within approximately 10,000 metres radius) or cause significant environmental concerns, medium-intensity obstacle lamps, Type C, should be used alone, whereas medium intensity obstacle lamps, Type B, should be used either alone or in combination with low-intensity obstacle lamps, Type B.

6.2.3.31 Where an object is indicated by medium-intensity obstacle lamps, Type A, additional lights shall be provided at intermediate levels. These additional intermediate lights shall be spaced as equally as practicable, between the top lights and ground level or the level of tops of nearby buildings, as appropriate, with the spacing not exceeding 105 m.

6.2.3.32 Where an object is indicated by medium-intensity obstacle lamps, Type B, additional lights shall be provided at intermediate levels. These additional intermediate lights shall be alternately low-intensity obstacle lamps, Type B, and medium-intensity obstacle lamps, Type B, and shall be spaced as equally as practicable between the top lights and ground level or the level of tops of nearby buildings, as appropriate, with the spacing not exceeding 52 m.

6.2.3.33 Where an object is indicated by medium-intensity obstacle lamps, Type C, additional lights shall be provided at intermediate levels. These additional intermediate lights shall be spaced as equally as practicable, between the top lights and ground level or the level of tops of nearby buildings, as appropriate, with the spacing not exceeding 52 m.

6.2.4.2 Recommendation.— The rotor blades, nacelle and upper 2/3 of the supporting mast of wind turbines should be painted white, unless otherwise indicated by an aeronautical study.
6.2.4.3 Recommendation.— When lighting is deemed necessary, in the case of a wind farm, i.e. a group of two or more wind turbines, the wind farm should be regarded as an extensive object and the lights should be installed:

a) to identify the perimeter of the wind farm;
b) respecting the maximum spacing, in accordance with 6.2.3.15, between the lights along the perimeter, unless a dedicated assessment shows that a greater spacing can be used;
c) so that, where flashing lamps are used, they flash simultaneously throughout the wind farm;
d) so that, within a wind farm, any wind turbines of significantly higher elevation are also identified wherever they are located; and
e) at locations prescribed in a), b) and d), respecting the following criteria:
    i) for wind turbines of less than 150 metres in overall height (hub height plus vertical blade height), medium-intensity lighting on the nacelle should be provided;
    ii) for wind turbines from 150 metres to 315 metres in overall height, in addition to the medium-intensity light installed on the nacelle, a second light serving as an alternate should be provided in case of failure of the operating light. The lights should be installed to assure that the output of either light is not blocked by the other; and
    iii) in addition, for wind turbines from 150 metres to 315 metres in overall height, an intermediate level at half the nacelle height of at least three low-intensity Type E lights, as specified in 6.2.1.3, should be provided. If an aeronautical study shows that low-intensity Type E lights are not suitable, low-intensity Type A or B lights may be used.

Note.— The above 6.2.4.3 e) does not address wind turbines of more than 315 metres of overall height. For such wind turbines, additional marking and lighting may be required as determined by an aeronautical study.

6.2.4.4 Recommendation.— The obstacle lamps should be installed on the nacelle in such a manner as to provide an unobstructed view for aircraft approaching from any direction.

6.2.4.5 Recommendation.— Where lighting is deemed necessary for a single wind turbine or short line of wind turbines, the installation should be in accordance with 6.2.4.3 e) or as determined by an aeronautical study.

Appendix E Extract of draft[22] TC Advisory Circular for ICAO VAWG

Advisory Circular

WINDTURBINE AND WINDFARM LIGHT1NG

DRAFT 7 - 18 July 2005

1. Scope:

This technical circular discusses the application of obstruction lighting for wind farm zones composed of wind turbines of heights between 90 and 150m [including the length of the blade] above ground level.

2. Definitions

Wind turbine. A device used for the generation of electricity from the wind. A wind turbine normally consists of a nacelle containing a generator and placed at the top of a support mast. At present, it is only practical to install lights on the nacelle rather than at tips of the blades ... thus the marking of the wind turbine is illuminated at a point which is much less than its true overall height.

Windfarm: A grouping of 3 or more wind turbines. Given that there is criteria to light the perimeter of a grouping, the first opportunity for which wind farm indicators [see below] may be applied at specified spacing is when there is more than 2 wind turbines.

Windfarm Indicators: Windfarm indicators are medium intensity lights installed on wind turbines of a wind farm such that their spacing of the former is not more than 900m.

Astronomical site: A location used for the purpose of carrying out astronomical activities such as an astronomical observatory, installation or observing site identified through public awareness.

Light Pollution: The production of glare and sky glow, by light sources, which can interfere with astronomic studies. Light pollution can also be harmful to night active birds which are attracted towards the light sources.

3. Reference Standards

International Civil Aviation Organization (ICAO), Annex 14, Volume 1, Aerodrome Design and Operation.

Illuminating Engineering Society, Lighting Handbook

Reference Organizations

American Bird Conservatory ... http://www.abcbirds.org/

Avian Power Line Interaction Committee ... http://www.aplic.org/

4. LIGHTING OF WIND FARM ZONES

4.1 Basic Principles

The purpose of lighting installed on structures, deemed to be obstacles to air navigation, is to alert the pilot in time for him/her to make a turning manoeuvre and thus avoid the structure by at least 600 m [2,000 ft]. This distance is derived from consideration of a communications tower of at least 2,000 ft height as shown in the figure below. In accordance with Visual Flight Rules [VFR], the pilot is to remain 500 ft Above Ground Level (AGL) and 500 ft from obstacles. For such a communications towers, the obstacle is actually the guywires which at the level of flight are 1,500 ft from the tower. In total, therefore, the

[22] This Advisory Circular was not adopted by Transport Canada. It does however indicate the thinking behind much of ICAO's work in this area.

distance of avoidance is 2,000 ft [500 + 1,500 = 2,000]. The visual acquisition distance is that required to make the turning manoeuvre dependent upon speed: 2.37 km [1.48 miles] for a 250 knot aircraft and 1.9 km [1.18 miles] for 165 knot aircraft.

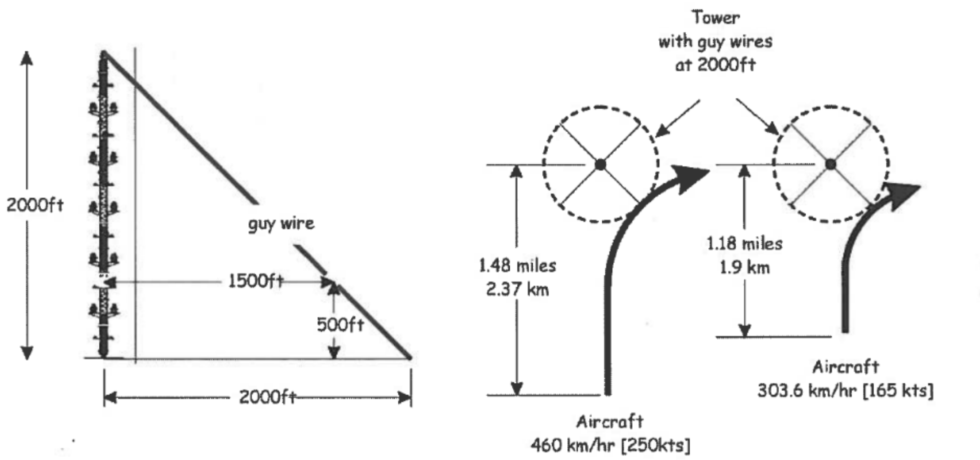


Figure D-1 Visual distance communication tower

Given the desired minimum acquisition distance, the required intensity of the lights can be calculated by using a derivation of Allard's Law:

$$I = E \cdot x^2 / T^2$$

Where E is the "illuminance" in lumens/km²

T is the luminous intensity in candelas

d is the distance in kilometres

T is the transmissivity per kilometre

This formula[23] can be resolved by means of a nomogram as shown below for 32 cd and 2,000 cd lights, for which the determined results listed in Table D-1. The 32 cd light can provide the required acquisition distance for 250 knot aircraft in 3 mile night visibility and the 2,000 cd light provides required acquisition for 165 knot aircraft in 1 mile night visibility.

Light intensity (candelas)	Acquisition Distance Kilometres (statute miles)	
	1 mile visibility	3 mile visibility
32	1.0 km (0.64)	2.4 (1.48)
2,000	1.9 (1.18)	4.8 (3.0)

Table D-1 Light intensity and acquisition distance

[23] This derivation of Allard's Law appears to be incorrect. It is quoted here as it was provided to ICAO by Transport Canada. The version in 8.1.3 is correct.

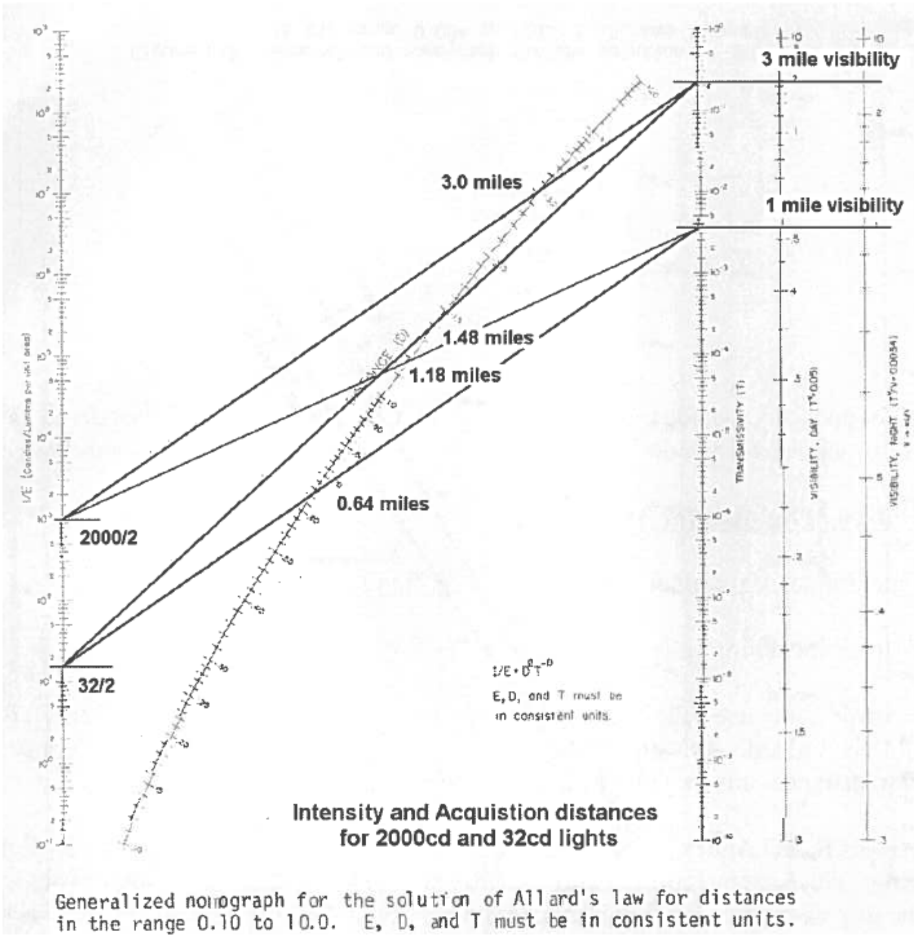


Figure D-2 Intensity and acquisition distances of 2,000 cd and 32 cd lights

Note: The above nomogram comes from a 1977 report to FAA, by C,A. Douglas and R.L. Booker (report FAA-RD- 77-8) for which a day and night visibility calibration curve for 500 foot baseline transmissometer [see below] has been incorporated along with Allard's Law.

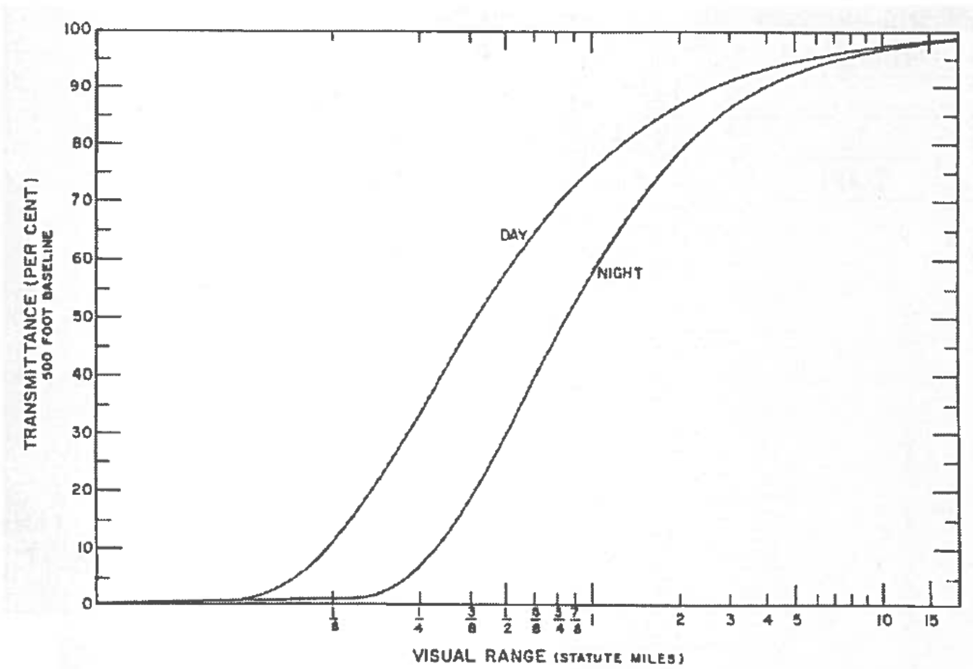


Figure D-3 Visual range

The 32 cd light does not provide night protection if 1 mile visibility is to be considered. However, it is not anticipated that an aircraft would be flying in 1 mile visibility at night and thus this case can be discounted.

4.1 Application of lighting for Wind farm zones

The basic operational requirement for wind farm lighting is 3 mile visibility.

In addition, the critical aircraft is assumed to be that having a speed of 165 knots. One might consider the use of low intensity lights to mark the wind farm. However, all of the wind turbines would need to be lighted. As well, the lights would be installed on the nacelle with only 2.4 km [1.48 miles] of acquisition distance, this may not be sufficient for night protection.

Article 6.3.14 of ICAO Annex 14 provides an alternative for use of medium intensity lights installed at 900 m spacing. This spacing comes from consideration of two 2,000 ft communications towers. The towers [actually the guy wires] become two separate objects when their distance apart exceeds 900 m [3,000 ft]. In the case of wind farm zones, the lights which are provided at 900 m spacing are referred to as "wind farm indicators". In order to enhance their display as being specific to a wind farm, these lights are to flash simultaneously. The figure below illustrates what these wind farm indicators would look like at the acquisition distance [1.9 km] for aircraft having a speed of 165 knots.

It is recognized that the medium intensity lights would be seen at 4.8 km [1.48 miles]. At such a distance the wind farm indicators would appear as being much closer than shown in the above drawing. The spacing of the wind farm indicators, however, that necessary to alert the pilot so that he/she does not elect to fly between the lights. Thus the display of this spacing, as shown in the drawing is required at the minimum distance necessary for making a turning manoeuvre.

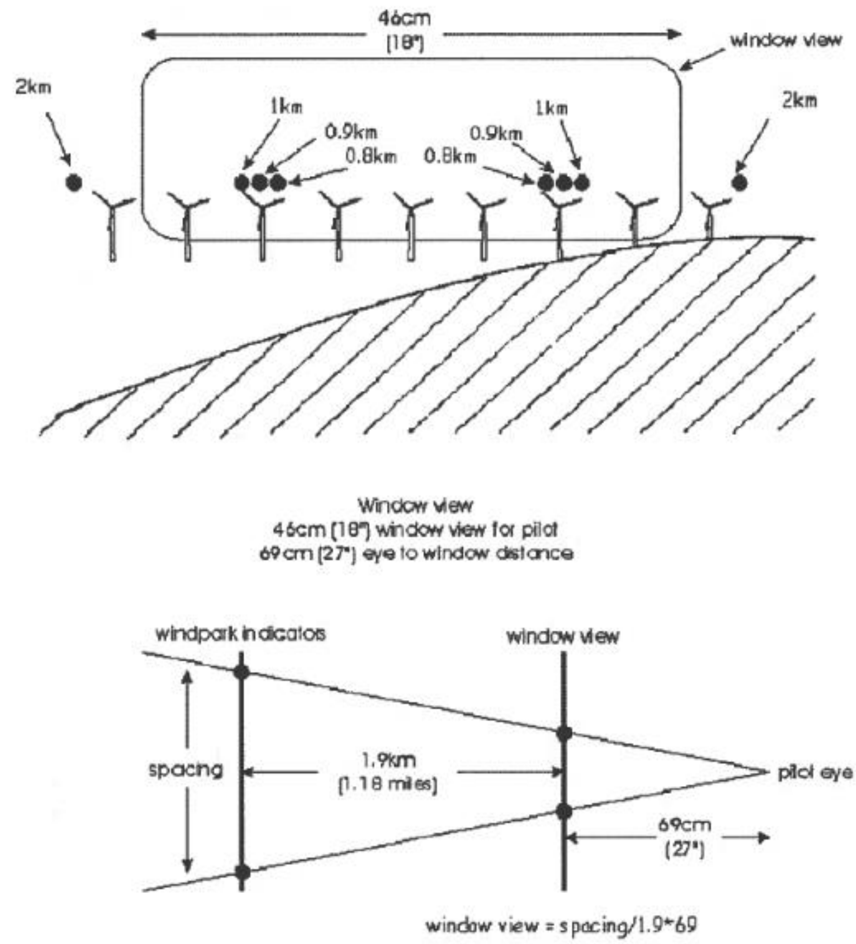


Figure D-4 Visibility wind turbines

It should be noted that the wind farm indicators can actually be acquired at 4.8 km [3 miles]. Thus the 900 m can be treated as a nominal value and there is some flexibility for application. Wind turbines may not be located at exactly 900 m distances.

5. OTHER FACTORS

5.1 Night Sky and Light Pollution

The clarity of night sky is of importance not only for the many people who casually or seriously maintain personal astronomical observatories, but also to our spiritual well-being. Unfortunately, by inappropriate use of lighting, we are progressively degrading our view of the night sky. Thus, the designer should pay particular attention to minimizing the adverse impact of lighting applied to wind farm zones. In general, red lighting should be used. The physiology of the human eye in low light levels is well understood. The eye is most sensitive to blue green light. Moreover, the sensitivity shifts significantly away from red, hence, red illumination sources do not contribute to the loss if night vision.

Appendix F Visibility Range

Regardless of the uncertainties regarding the maximum distance at which an observer can perceive objects in the distance, it is assumed that an object at 20 km from the coast will be visible on a clear day. The question arises as to how often the visibility is or exceeds 20 km along the Dutch North Sea coast.

The Dutch meteorological institute, KNMI, has a network of over 20 stations in the Netherlands that collect, among other data, visibility data. Analyses made in earlier studies are repeated here. The studies used are Environmental Impact Assessments (*Milieueffectrapport* or MER). Data from the coastal stations at Vlissingen[24], Hoek van Holland, Ijmuiden and De Kooy (Den Helder) is reported below for differing periods of time. Visibility is calculated by KNMI in the basis of the measurement of water particles in the air. Summer is defined as being between 1 May and 30 September. Night-time is defined as being between 21:00 in the evening and 07:00 in the morning.

Visibility	**Percentage of time (whole year)**	**Percentage of time (summer)**	**Percentage of time (summer, day time)**
>5 km	81.6 %	89.6 %	91.8 %
>10 km	61.5 %	72.0 %	75.6 %
>20 km	29.3 %	38.0 %	42.1 %
>30 km	6.9 %	10.4 %	12.8 %

Table E-1 Visibility data for the KNMI weather station at Vlissingen for the period 1955 – 2014 (Source: Pondera)

Based on the proposed locations for two sites of the Borssele wind farm, Borssele I and Borssele II, the MERs concluded that the average visibility in the summer (May to September, inclusive), when measured from the closest point on land to the wind farm zones, Westkapelle or Domburg, would be as follows:

Location	**Distance**	**Percentage of time that location is visible in summer**
Borssele I	27 km	11.5 %
Borssele II	24 km	22.4 %

Table E-2 Percentage of time that Borssele I and II will be visible from closest points onshore in summer (Source: Pondera)

Similar tables were published in the MER for visibility data at the KNMI weather station at IJmuiden[25] for the summer period 1971 – 2002. Summer, in this case, is defined as the period between 1 May and 1 October. Daylight is, as before, the period between 07:00 in the morning to 21:00 in the evening. The one

[24] *Milieueffectrapport kavelbesluit I windenergiegebied Borssele* and *Milieueffectrapport kavelbesluit II windenergiegebied Borssele*, both Grontmij & Pondera, June 2015

[25] *Milieueffectrapport Kavel I Windenergiegebied Hollandse Kust (Zuid)*, and *Milieueffectrapport Kavel II Windenergiegebied Hollandse Kust (Zuid)*, both Pondera, May 2016

day's difference between the reporting periods may be explained by a reporting error. If not, a single day's data is not considered significant.

Visibility	Percentage of time (whole year)	Percentage of time (summer)	Percentage of time (summer, day time)
>5 km	83.1 %	89.2 %	88.6 %
>10 km	56.8 %	66.5 %	66.8 %
>20 km	19.9 %	24.8 %	26.0 %
>30 km	6.3 %	9.4 %	10.6 %

Table E-3 Visibility data for the KNMI weather station at IJmuiden for the period 1971 – 2002 (Source: Pondera)

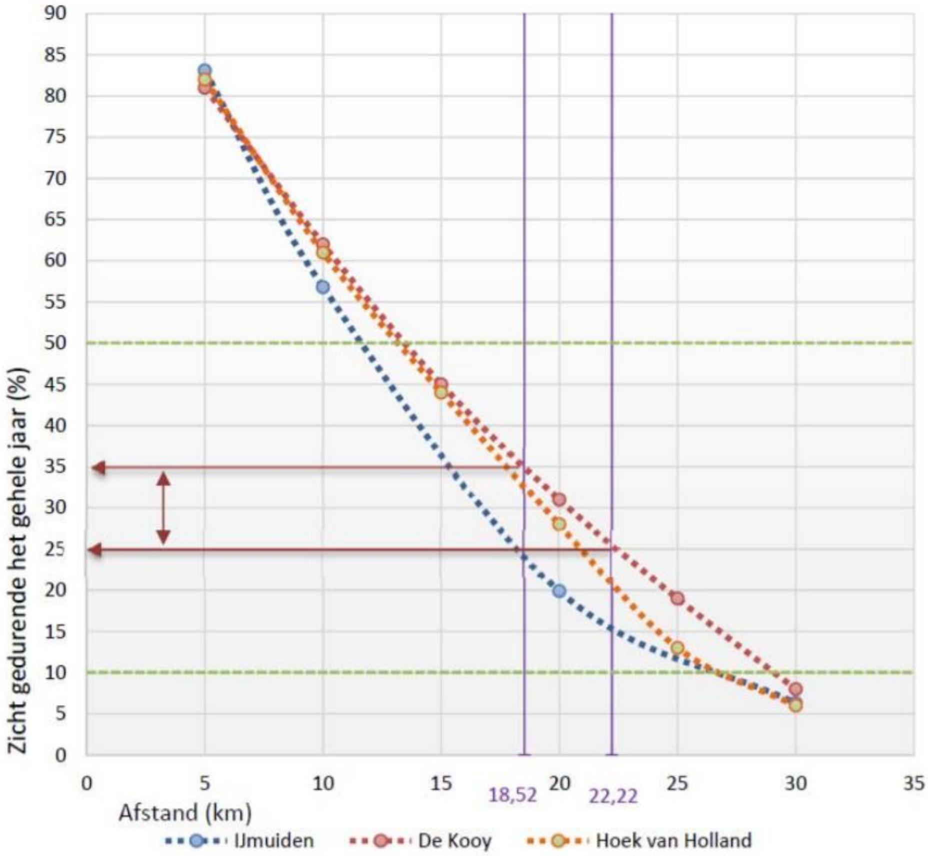
Based on the proposed locations for two sites of the Hollandse Kust (zuid) wind farm, Hollandse Kust (zuid) I and Hollandse Kust (zuid) II, the MERs concluded that the average visibility in the summer (May to September, inclusive), when measured from the closest point on land to the wind farm zones, Noordwijk for Site I and Scheveningen for Site II, would be as follows:

Location	Distance	Percentage of time that location is visible in summer
Hollandse Kust (zuid) I	22.2 km	17.25 %
Hollandse Kust (zuid) II	23.6 km	16.83 %

Table E-4 Percentage of time that Hollandse Kust (zuid) I and II will be visible from closest points onshore in summer (Source: Pondera)

A third study[26] examined visibility data for the weather stations at IJmuiden, Hoek van Holland and De Kooy (Den Helder). The results of that work were presented in the graph shown below.

[26] *Plan MER en PB windenergie op zee binnen 12mijlszone, Royal Haskoning DHV & Grontmij, May 2016*



Figuur 25: Zicht gedurende het gehele jaar (% van de tijd overdag) uitgezet tegen de afstand (in km) voor drie weerstations van het KNMI: Hoek van Holland, IJmuiden en De Kooy.

Figure E-1 Visibility from three KNMI stations (Source: Royal Haskoning DHV & Grontmij)

The data shows that for the period reviewed[27], the best visibility along the coast was recorded at Den Helder. However, for all three locations, the daytime visibility exceeds 20 km for between 20 and 30 percent of the time. The study concluded that the visibility of wind turbines is "… strongly dependent on the brightness of the weather and the distance between observer and object. Many people will see that something is' but often not see clearly "what" it is".

As a final point, it should be noted that the documents reviewed did not explicitly refer to the visibility of lamps on wind turbines at night.

[27] The exact period is not reported in the source. It is stated that the data was collected over many years "*langjarige*".

Appendix G 900 metre field of view

ILT *Informatieblad*; and the regulations and guidelines published by the United Kingdom, Denmark, Canada & Australia assume a 900 metre field of view, as illustrated in the figure below.

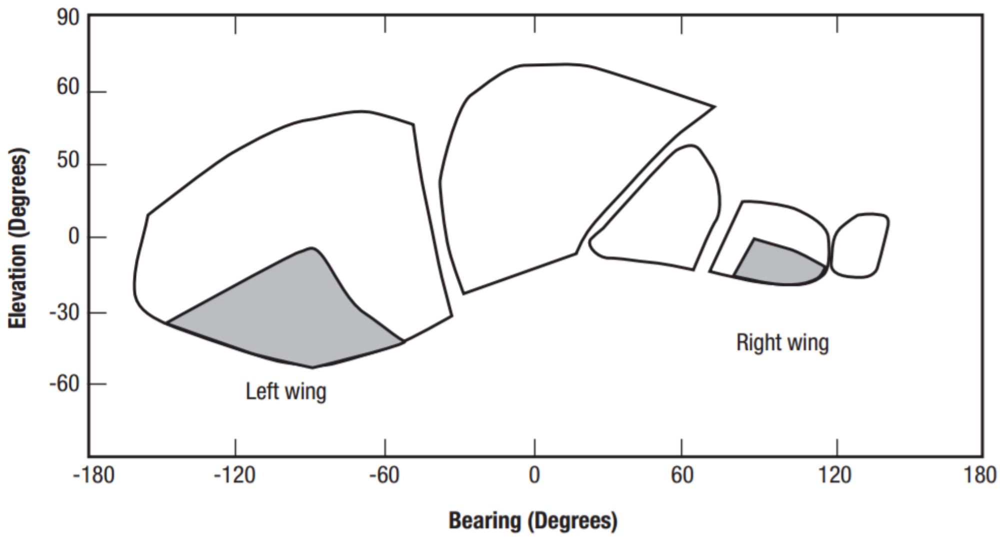


Figure F-1 ATSB report showing field of sight limitations for a general aviation aeroplane

It should be noted that the above data is optimised for flight crew recognition of the objects flying at a speed of 165 knots. A 1991 study[28] by the Australian Transportation Safety Board (ATSB) demonstrated the field of sight limitations that apply to the typical general aviation aeroplane as flown by a single pilot.

However, the limitations are not unrealistic for the operations that may take place in and around the wind farm zones. The visibility figure of 1,900 metres, or 1.03 NM, is low for many of the expected visual operations. The aperture that is used in the figure above is not realistic for either two-crew aeroplanes, such as the Dornier 228 from the Coastguard or the broad cockpits of helicopters. The origin of this work is, according to the ICAO VAWG, the result of an analysis conducted for the FAA to justify the structure and marking of 2,000 feet tall towers and supporting guy wires that are designed to be passed at a range of 1,500 feet (0.25 NM). Whilst no specific data has been identified, the use of two crew aircraft in operations above and in the wind farm zones, increases the field of sight that crews have.

[28] Limitations of the See-and-avoid Principle, ATSB, April 1991

Appendix H Notes on camouflage testing

These tests consisted of observations of three 4-metre-tall scale model wind turbines, each with a different colour / pattern, being viewed from about 300 metres. This corresponds to a wind turbine of about 200 metres tall being viewed from 18.5 kilometres. The test was intended to simulate a viewer looking at an object on the horizon. A similar experiment could be considered for a group of wind turbines viewed from different ranges and different altitudes (e.g. 500 feet, 1,000 feet and 2,500 feet altitude and 5 kilometres, 8 kilometres and 12 kilometres range).

Three different wind turbine masts and blades were simulated as shown in the image below. A fourth, blue polychromatic, blade was not tested.

		
Standard White		**Black and White**
		
Grey & Green		**Blue, polychromatic**

Figure G-1 Wind turbine blades used for visibility testing

Over three days, a total of 18 different light conditions were encountered. These were recorded (on film and on paper) by a cameraman. A summary of the light conditions is contained in the following table.

Observations		**A - E**	**F**	**G**	**H**	**I - L**	**M1**	**M2**	**N**	**O**	**P**	**Q**
General	Clear	X	X					X				X
	Cloudy			X	X	X			X	X	X	
	Mist / fog						X					
	Low cloud											
	Inversion layer											
Wind direction	Easterly	X	X	X	X	X						
	Westerly											
	Northerly											
	Southerly						X	X	X	X	X	X
Air humidity	low	X	X									
	average			X	X	X				X	X	X
	high						X	X	X			
Wind strength	0 - 2 BFT						X	X	X	X	X	X
	3 – 4 BFT	X	X	X	X							
	>= 5 BFT											
Orientation sun	Fore		X	X	X							
	Aft											
	Diagonal fore											
	Diagonal aft	X								X	X	X
	No direct sun					X	X		X			
Sun strength	Weak			X	X	X	X		X	X		
	Strong	X	X					X			X	X

Table G-1 Light conditions during visibility testing

Appendix I References

Regulations

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- Notice of Proposed Amendment 2016-04, EASA, June 2016 (see CS ADR-DSN.Q.841 to 852)
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- Canada: Canadian Aviation Regulations, Standard 621 - Obstruction Marking and Lighting, Transport Canada, 1 March 2016
- Denmark: Statens Luftfartvaesen, BL 3-10, Bestemmelser om luftfartshindringer
- Finland: Finnish Transport Safety Agency, Instructions for daytime signalling of wind turbines, aircraft warning lights and the grouping of lights,
- Germany: Bundesministerium für Verkehr, Bau und Stadtentwicklung, Allgemeine Verwaltungsvorschrift zur Kennzeichnung von Luftfahrthindernissen
- UK Civil Aviation Authority, Air Navigation: The Order and Regulations
- UK: CAP 437 - Standards for Offshore Helicopter Landing Areas, UK Civil Aviation Authority, February 2014

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- *Informatieblad Annduiding Offshore windturbines en offshore windparken in relatie tot luchtvaartveiligheid*., ILT, version 3 dated 30 September 2016
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- Press Release - Omwonenden Prinses Alexia Windpark willen constant brandende verlichting, Windenergie Courant, 1 September 2015
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- Factsheet: Windenergie op Zee, Natuur en Milieu

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- Wind turbines and Aviation Interests – European Experience and Practice, STASYS Ltd for UK DTI, 2002
- Wratten, A., Martin, S., Welstead, J., Martin, J., Myers, S., Davies, H. and Hobson, G. (2005) The Seascape and Visual Impact Assessment Guidance for Offshore Wind Farm Developers, Enviros Consulting and Department of Trade and Industry
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- Radar based On-demand Lighting System, Vangen, 2011

Other material

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